AD-A036 333 ARMY ELECTRONICS COMMAND FORT MONMOUTH N J F/G 4/1

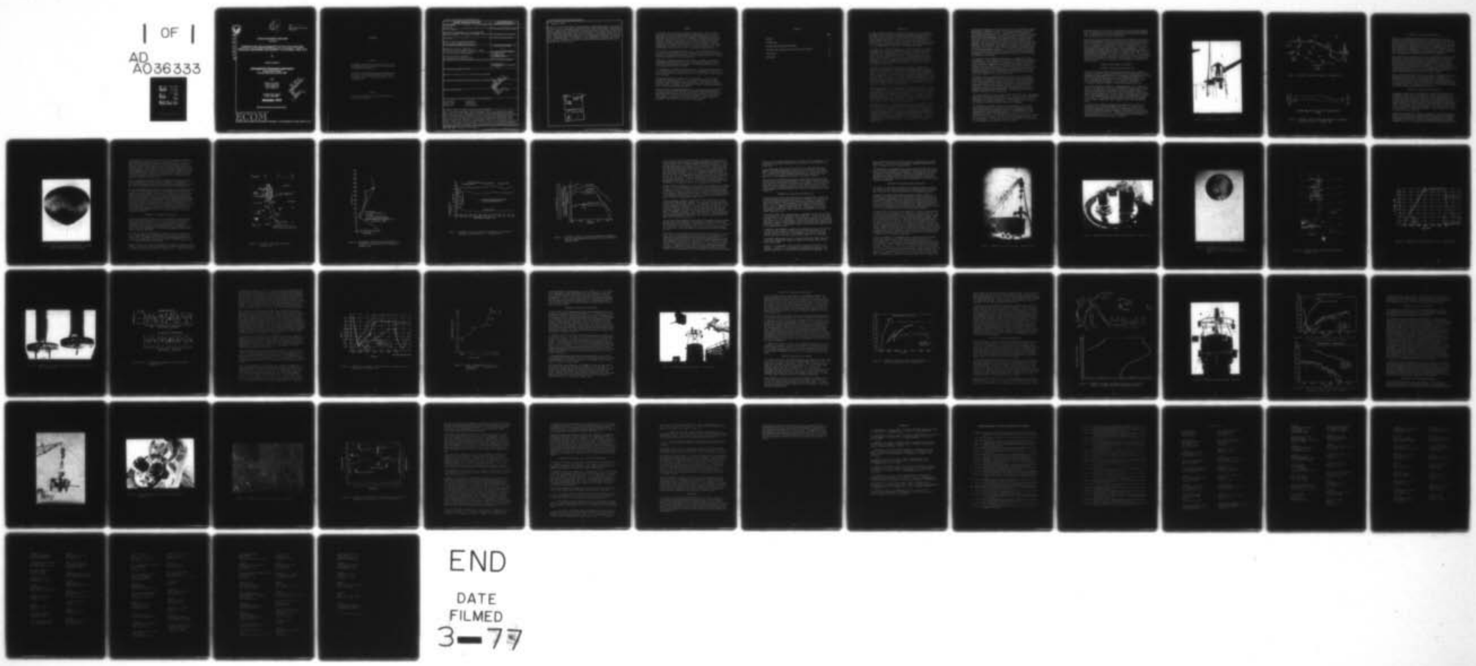
TEMPERATURE MEASUREMENTS IN THE STRATOSPHERE FROM BALLOON-BORNE--ETC(U)

DEC 76 H N BALLARD, M IZQUIERDO, C MCDONALD

UNCLASSIFIED ECOM-5808 NL

1 OF 1

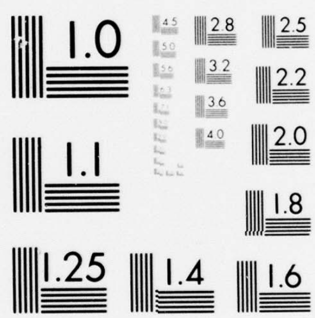
AD A036333



END

DATE FILMED

3-77



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD

Reports Control Symbol
OSD-1366

RESEARCH AND DEVELOPMENT TECHNICAL REPORT
ECOM-5808

TEMPERATURE MEASUREMENTS IN THE STRATOSPHERE FROM BALLOON-BORNE INSTRUMENT PLATFORMS, 1968-1975

By

Harold N. Ballard

Atmospheric Sciences Laboratory
US Army Electronics Command
White Sands Missile Range, New Mexico 88002

and

Miguel Izquierdo
Carlos McDonald
John Whitacre

University of Texas at El Paso
El Paso, Texas 79902

December 1976

Approved for public release; distribution unlimited.

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND - FORT MONMOUTH, NEW JERSEY 07703

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of trade names and names of manufacturers in this report is not to be construed as official Government indorsement or approval of commercial products or services referenced herein.

Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ECOM-5808	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): TEMPERATURE MEASUREMENTS IN THE STRATOSPHERE FROM BALLOON-BORNE INSTRUMENT PLATFORMS, 1968-1975	5. TYPE OF REPORT & PERIOD COVERED: Research and development technical rept.
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Harold N. Ballard, Miguel Izquierdo, Carlos McDonald, and John Whitacre	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico 88002	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: DA Task No. 1L161102B53A
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Electronics Command, Fort Monmouth, New Jersey 07703	12. REPORT DATE: December 1976
	13. NUMBER OF PAGES: 54
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Stratosphere	Variations
Diurnal tide	Temperature
Thermistors	Balloon-borne

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Within the period September 1968 to September 1975, six balloon-borne experiments under the title "Stratospheric Composition Experiments" were conducted. These experiments were originally designed to measure the temperature variations near an altitude of 50 km that were to be associated with the diurnal tide. Requirements by the Department of Defense for information concerning stratospheric composition, as well as measurements of interest to the possible pollution of the stratosphere by the Supersonic Transport and by the chlorofluorocarbons, gradually increased the number, types, and complexity of measurements conducted

next page

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (cont)

during each successive flight. Measurements of temperature, however, continued to serve as basic background data for the composition measurements. During each flight, something was learned about techniques, sources of thermal contamination, and operational procedures which must be followed to accurately measure the correct atmospheric temperature with the balloon-borne film-mounted thermistor sensors. The temperature data obtained in the stratosphere from these six flights gives information which is indicative of the temperature variations which occur at a specific altitude in a parcel of air moving with the balloon within time intervals of 3 to 12 hours.

SUMMARY

A comparison of the payload photographs demonstrates that the number, type, and complexity of measurements conducted during the STRATCOM VI experiment of 1975 increased significantly from those made during the STRATCOM I experiment of 1968. The STRATCOM VI payload represents the combined experience and expertise of personnel of several government agencies, numerous research laboratories, and organizations working cooperatively to obtain experimental data which contribute to an understanding of the interrelated chemical, charged particle, thermal, and hydrodynamic processes which occur in the complex stratosphere.

The incentive for the fabrication of such a payload had its origin in the attempt to understand the large difference which originally existed between the observed and theoretically predicted amplitude of the diurnal temperature variation in the stratosphere.

Based upon the data presented in this report, accurate measurements of stratosphere temperature can be made by film-mounted spherical bead thermistor sensors aboard balloon-borne instrument payloads, provided some logical precautions are taken.

The temperatures recorded by these sensors are influenced by the presence of the large balloon, if the balloon is at a temperature different from that of the surrounding atmosphere and if the sensors are in the proximity of the balloon.

The balloon remains much colder than the atmosphere, after it passes through the tropopause, when it is launched so as to reach its float altitude in the stratosphere during the night. After sunrise, the balloon is heated by incident solar radiation, finally reaching temperatures warmer than the surrounding atmosphere.

By mounting the film-mounted thermistors in the configuration described in the discussion of the STRATCOM III experiment and by separating the payload-mounted sensors as far as experimentally practical from the balloon surface (2 to 3 balloon diameters), accurate ($\pm 1°C$) measurements of atmospheric temperature can be made directly, without recourse to theoretical corrections to the observed temperatures.

CONTENTS

INTRODUCTION

By 1968, balloon technology had progressed to the point a constant-altitude balloon carrying an atmospheric parameter sensing payload of 60 pounds could be launched to an altitude of approximately 50 km. Data concerning stratospheric winds, gathered by the Meteorological Rocket Network (MRN) over a period of 10 years, made possible the prediction of the ensuing balloon trajectory. These two factors led to six integrated experiment balloon flights into the stratosphere under the name Stratospheric Composition (STRATCOM) experiments.

The program was initially designed by the Army's Atmospheric Sciences Laboratory (ASL) at White Sands Missile Range (WSMR), New Mexico, in cooperation with the Aerospace Instrumentation Division of the Air Force Geophysics Laboratory (AFGL) with contract support from the University of Texas at El Paso (UTEP). The program objective was to determine the salient features of atmospheric tides in the 30-60 km atmospheric region, with particular attention being given to the determination of the magnitude of the diurnal temperature variation associated with the tide.

The authors felt that all that would be required to emphatically establish experimentally this temperature variation and its magnitude would be to simply place a slightly modified rocketsonde temperature sensor in the form of a spherical bead thermistor on the balloon platform and cause the balloon to float at a constant altitude near 50 km for a period of 24 hours. The observed difference between the measured temperature minimum and maximum values would then be the desired diurnal tidal temperature variation near 50 km. The six flights conducted in the period 1968-1975 served to prove that the authors were, at least initially, somewhat naive in this regard.

Since the magnitude of the temperature variation at a specific altitude in the stratosphere is related to the solar ultraviolet (uv) radiation and atmospheric composition at that altitude, the STRATCOM I balloon of 1968 served as a constant level support near 48 km for a scientific payload weighing 59 pounds and consisting of six instruments for the measurement of atmospheric temperature, pressure, density, and related ozone and water vapor concentrations. No capability existed within ASL, at that time, to measure the solar uv flux.

Additional flights were conducted in September 1969, September 1972, October 1973, May 1974, and September 1975 and were entitled STRATCOM II - STRATCOM VI, respectively. The number and types of instruments on each successive balloon flight were increased to give additional information concerning the relationship among the various atmospheric parameters through their simultaneous measurement at successive points in space and time along the various balloon trajectories. This was made possible within the indicated time frame only through the participation of other laboratories with existing atmospheric research capabilities.

Particularly noteworthy in this regard was the participation by Sandia Laboratories, Albuquerque (SLA), of the Energy Resources Development Administration beginning in 1971. Experimentally this added mass spectrometry and ultraviolet spectroscopy to the measurement techniques aboard the STRATCOM payloads; of equal importance, it made available the extensive instrumentation development and field experimentation experience of SLA. It was at this point that the correlated multi-instrument measurement approach, backed by chemical kinetic theory and modeling, was initiated. This approach resulted in the September 1972 STRATCOM III balloon-borne experiment which carried 17 instruments to an altitude of 48 km to measure solar uv radiation, atmospheric composition and thermodynamic structure. A useful technique was developed and utilized during this balloon flight to determine the atmospheric temperature from balloon-borne temperature sensors, without resorting to theoretical corrections.

The objective of the STRATCOM experiments, as related to the study of atmospheric tidal temperature variations, was addressed during each flight; however, requirements by the Department of Defense for information concerning stratospheric composition and thermal structure as related to nuclear defense, and measurements of interest which are related to the possible pollution of the stratosphere by the Supersonic Transport and by the chlorofluorocarbons gradually modified and increased the number, types, and complexity of measurements conducted during the STRATCOM IV, V, and VI experiments.

STRATCOM IV and V, launched October 1973 and May 1974, respectively, were primarily dedicated to the measurement of oxides of nitrogen, water vapor, and ozone by a laser opto-acoustic technique developed by Bell Laboratories and fielded through their relationship with SLA. Measurements made by other instruments aboard these balloon-borne platforms in the 19-28 km altitude interval, particularly by the temperature and water vapor instruments, indicate that little new information was gained from these flights concerning the unperturbed thermal structure of the stratosphere.

The sixth experiment in the series, termed STRATCOM VI, was a two-balloon experiment conducted 23-26 September 1975. It was directly or indirectly supported by six federal agencies with participation by ten federal, university, and private laboratories. Coordination with U-2 aircraft and NIMBUS-6 satellite-based measurements was arranged.

The STRATCOM VI-b payload, lifted on 26 September by a 2.9 million cubic foot balloon to an altitude of 30 km, was devoted to making specific measurements related to the possible contamination of the stratosphere by the chlorofluorocarbons. The STRATCOM VI-a balloon supported a payload of 29 instruments which was borne aloft on 23 September by a 15.6 million cubic foot balloon to measure the related solar uv flux, atmospheric composition and thermodynamic structure in the stratosphere. Film-mounted spherical bead thermistor again served as the atmospheric temperature sensing elements.

Presented below are the balloon characteristics, the payload configuration, the horizontal and vertical trajectory, and the measured temperatures as functions of time for each balloon-borne experiment, STRATCOM I-VI, conducted within the period 1968-1975.

During each flight information was obtained on techniques, sources of thermal contamination, and operational procedures which must be followed. Each of these items is briefly discussed as it relates to modifications which were made in each succeeding instrument configuration so as to measure accurately, without having to resort to theoretical correction, the atmospheric temperatures existing in the stratosphere. A proper combination of balloon characteristics, payload weight, adequate ballast, and favorable winds permitted a flight of 33 hours within the 27-40 km interval for the STRATCOM VI-a flight of September 1975. The temperature data obtained during this experiment, coupled with similar data obtained during the five previous experiments, are indicative of the temperature variations which occur at a specific altitude within time intervals of 3 to 12 hours.

STRATCOM BALLOON-BORNE EXPERIMENTS

STRATCOM I Experiment Description [1]

A helium-filled zero pressure polyethylene balloon, with a material thickness of 0.45 mil and a total volume of 28.7 million cubic feet was designed and fabricated jointly by the Aerospace Instrumentation Division of AFGL and Winzen Industries, Inc., and launched from WSMR (32° N, 106° W) by the Balloon Branch of AFGL located at Holloman Air Force Base (Holloman AFB), New Mexico. The balloon was launched on 11 September 1968 and reached a then record altitude of 48.5 km.

The balloon experiment required a supporting frame for six atmospheric sensors. The payload in its final configuration consisted of aluminum frame and ballast exit, central power supply and sensor modulation circuitry; two 1680 MHz transmitters and six atmospheric sensors with their associated mountings. Figure 1 shows the payload and the arrangement of the atmospheric sensing instruments. Two temperature sensors in the form of film-mounted spherical bead thermistors were mounted on hollow glass epoxy rods which extended 3 feet below the aluminum frame.

The balloon was launched at 0558 MST and reached its initial float altitude of 48.5 km at approximately 0830 MST. The plot of the horizontal trajectory of the balloon is presented in Figure 2; the balloon altitude and measured atmospheric temperature as functions of time are presented in Figure 3. Seventeen hours of stratospheric data were obtained in the 48.5 to 45.5 km height interval over a path extending from WSMR to Palm Springs, California.

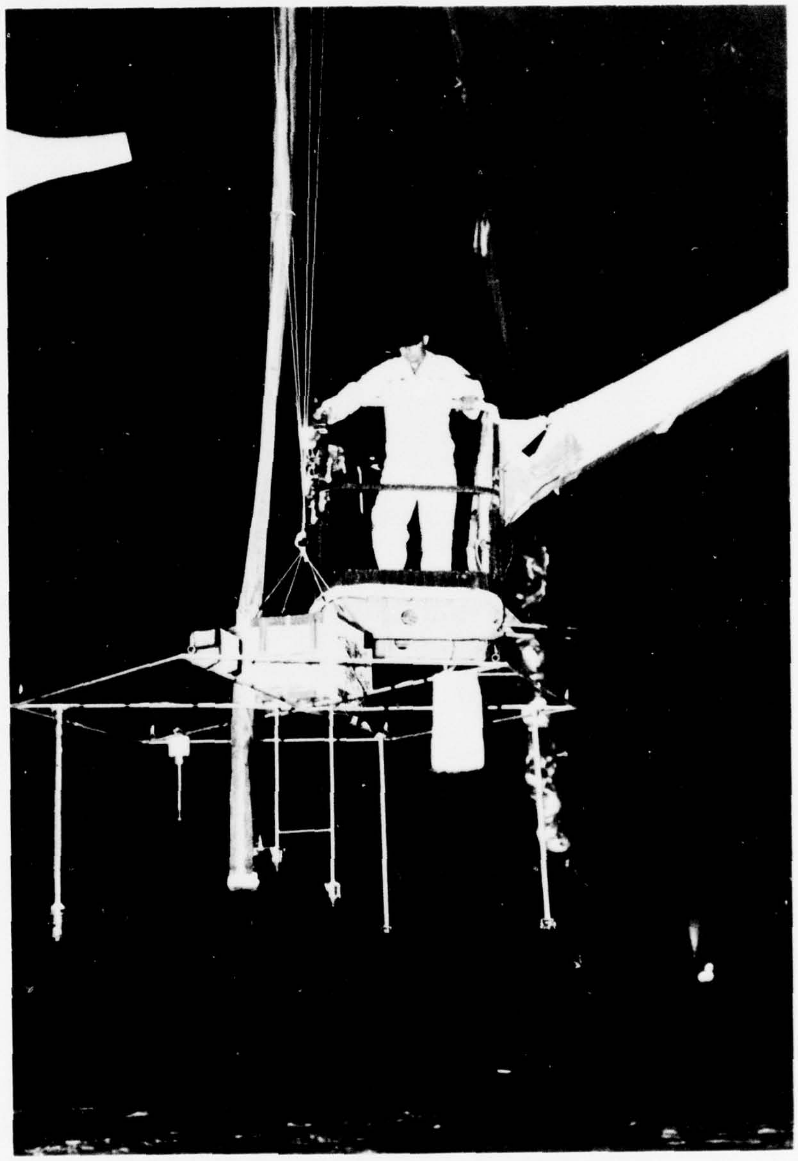


Figure 1. STRATCOM I payload - September 1968.

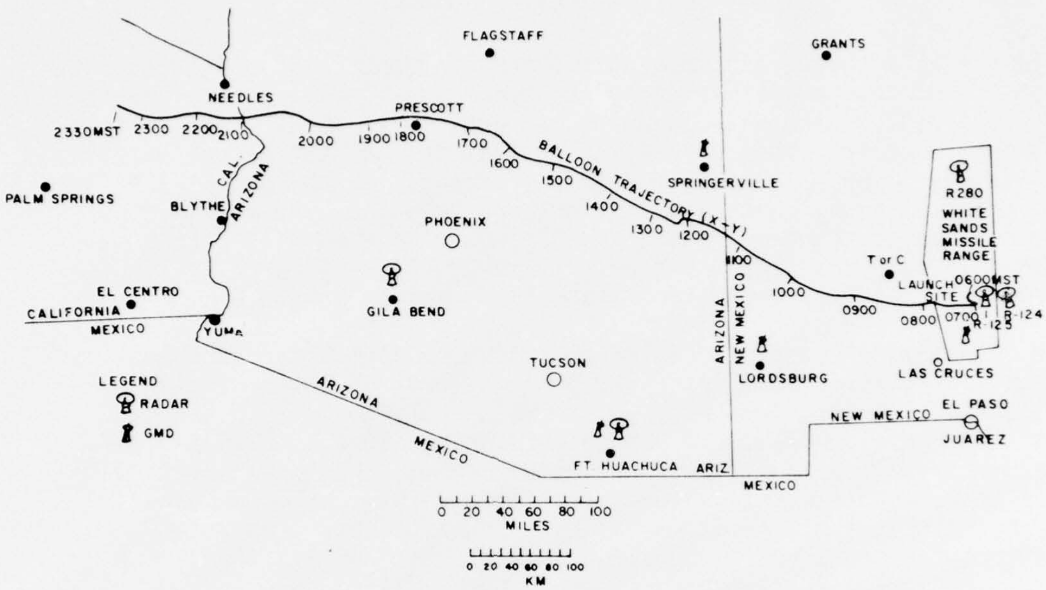


Figure 2. STRATCOM I horizontal trajectory - September 1968.

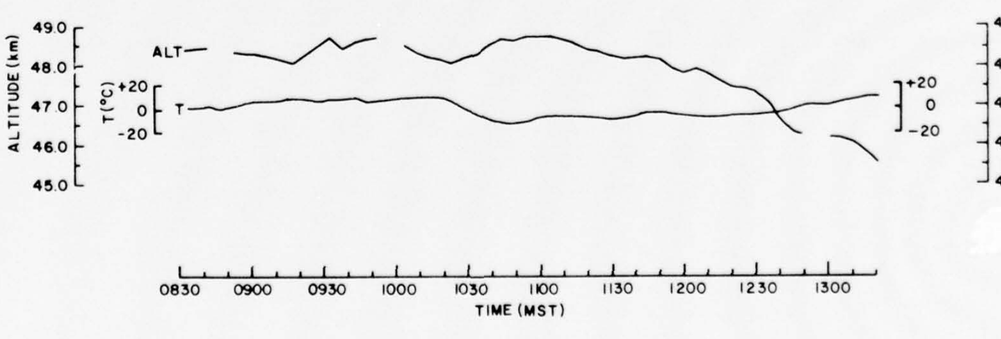


Figure 3. STRATCOM I balloon altitude and atmospheric temperature as functions of time - September 1968.

STRATCOM I Temperature Measurements

Figure 4 is a photograph showing the fully expanded balloon at an altitude of 48.5 km with the payload suspended 64 feet (19 m) beneath the lower end of the balloon which had a diameter of 410 feet (124 m). Balloon launching procedures dictated that the payload be not more than this distance below the balloon at the time of launching. At the time the experiment was conducted, the authors felt that the proximity of the balloon to the temperature sensors would have an effect (the magnitude uncertain) on the atmospheric temperatures registered by the sensors. Not knowing, the authors took the simplest approach.

The temperature measured near 48 km by the balloon-borne spherical bead thermistors, which were identical in configuration to a rocket-borne temperature sensor fired from WSMR, was approximately 10°C greater than the rocketsonde-determined temperature at 48 km. Even though the horizontal variability of the atmosphere was not known, this difference between the temperatures registered by the balloon-borne and rocket-borne thermistor at 48 km was interpreted as an indication of the perturbation produced in the actual atmospheric temperature by the large, warmer-than-atmosphere balloon at that altitude.

Thus the decision was made for the next flight, to separate the sensing payload from the balloon by a reel-down mechanism which was to be activated after the time of balloon launching. In addition, it was felt that it was necessary to have knowledge of the temperature of the surface of the balloon. This implied that an instrument package with a temperature sensor attached to the skin of the balloon would be mounted on the apex plate of the STRATCOM II balloon.

STRATCOM II Experiment Description [2]

The second of the series of stratospheric composition experiments was launched to a then new record altitude of 50.0 km from WSMR, NM, on 22 September 1969. The 30.7 million cubic foot helium-filled, zero-pressure, polyethylene balloon supported an instrument payload consisting of bead thermistor atmospheric and balloon-skin temperature sensors, thermal conductivity pressure gage, a forward-scattering beta-ray atmospheric density gage, two chemiluminescent ozonesondes, a Geiger tube cosmic ray detector, and an accelerometer for the determination of the vertical component of balloon acceleration. Radar position-time served to determine the wind velocity.

The balloon had a material thickness of 0.45 mil with a corresponding weight of 1533 pounds. The total payload weight, including instrument control package and radar reflector, was 451 pounds, which included 228 pounds of ballast and a sensing payload of 70 pounds. When fully expanded near 50 km, the balloon had a mean diameter of 442 feet (134 m).

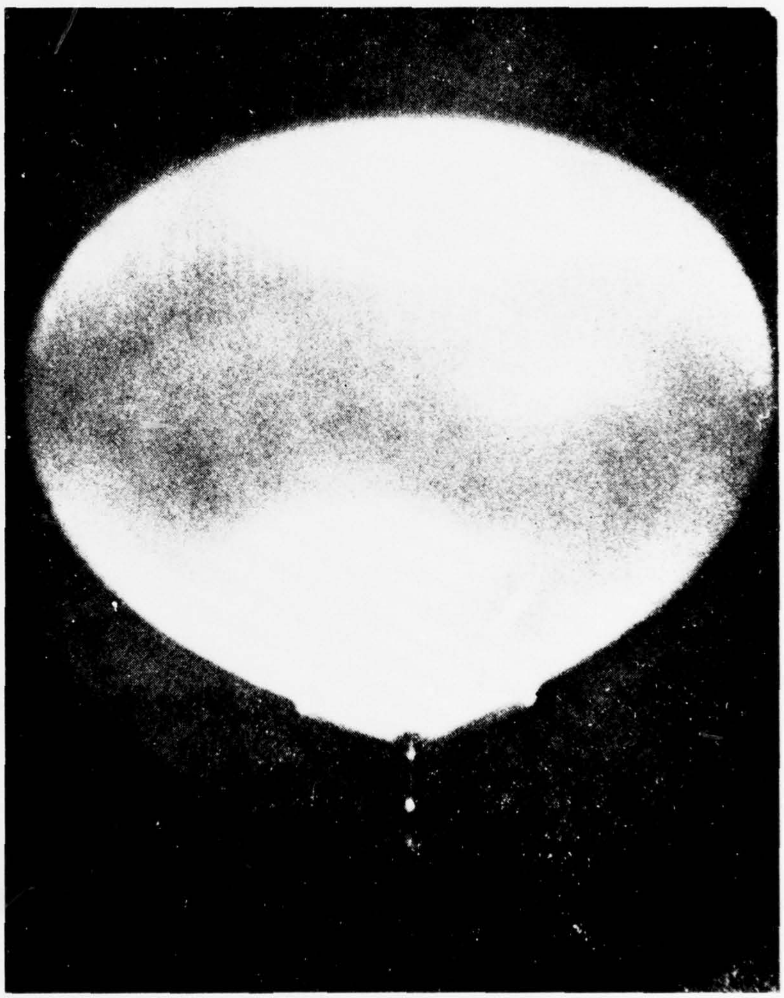


Figure 4. Fully expanded balloon STRATCOM I - September 1968. Payload 64 ft beneath balloon.

The atmospheric sensing instrument payload configuration beneath the balloon was essentially the same as that shown in Figure 1. Again the two film-mounted spherical bead thermistor temperature sensors were mounted on hollow glass epoxy rods which extended 3 feet below the instrument frame. A reel-down mechanism was placed between the balloon control package and the payload. This permitted the separation of the sensing payload, after balloon launching, from the immediate vicinity of the large balloon. Mechanical considerations limited the maximum distance of separation between the lower end of the balloon and the sensing payload to 1056 feet (320 m).

A 10-mil spherical bead thermistor was attached to the surface of the balloon approximately 4 feet from the periphery of the apex plate. Balloon skin temperature data were transmitted to a ground-based receiver by a 1680 MHz transmitter mounted on the apex plate of the balloon.

The horizontal projection of the balloon trajectory is shown in Figure 5. A total of 17 hours and 34 minutes of atmospheric data was obtained between the time of balloon launching at 2336 MST on 22 September and balloon flight termination at 1710 MST on 23 September with recorded data from an atmospheric region, all points of which were within 200 km of the launch site. The balloon reached its designed float altitude of 48.5 km at 0545 MST on 23 September. It was during this relatively long ascent period of 6 hours that the authors first learned that instruments need to be extremely well insulated to survive the extremely cold temperatures (-70°C to -40°C) created by the environment and in the wake of a balloon which remained at a temperature of -55°C until it was heated by radiation from the sun after the time of sunrise at the balloon altitude.

STRATCOM II Temperature Measurements

Of the many interesting features of the temperature records obtained during this flight and which are discussed in detail in the above-listed reference, figures 6, 7, and 8 are illustrative of items for consideration when making accurate measurements of stratospheric temperature from balloon-borne instrument payloads, or drawing conclusions from these measurements concerning the magnitude of the diurnal tidal temperature variation.

A comparison among the temperature records of Figure 6 obtained from the indicated radiosonde, rocketsonde, and balloon-borne temperature sensors shows the marked effect of the colder-than-atmosphere balloon surface on the atmospheric temperature sensors following upward in the balloon wake during the time of ascent.

Figure 7 presents the balloon altitude and atmospheric temperature sensor records as functions of time between 0600 and 1200 MST when the balloon was floating between the altitudes of 48 and 50 km. It shows, after the

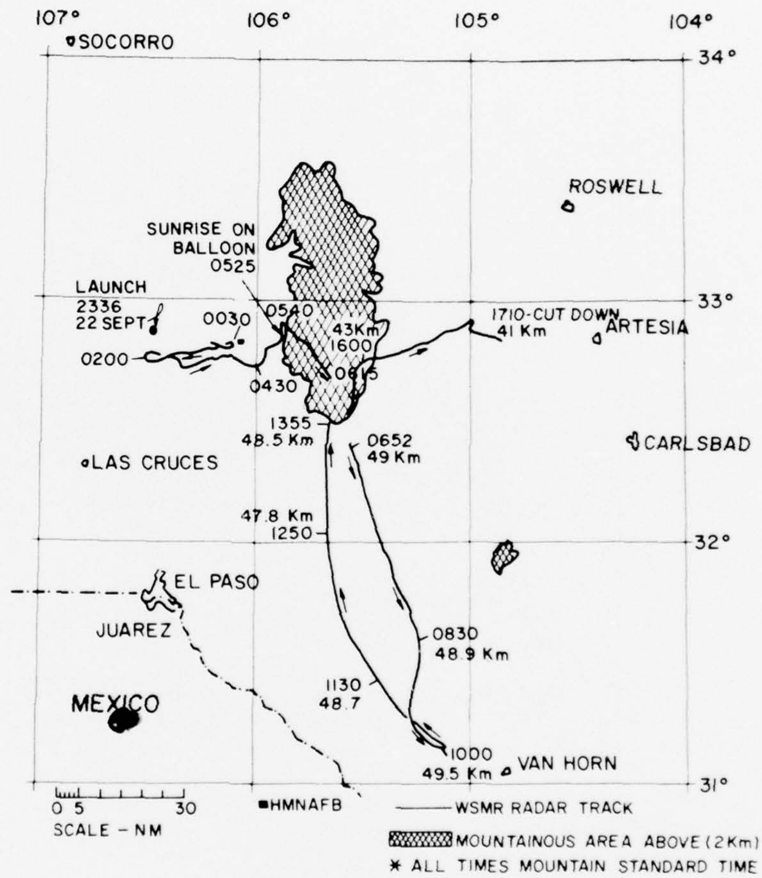


Figure 5. STRATCOM II horizontal trajectory - September 1969.

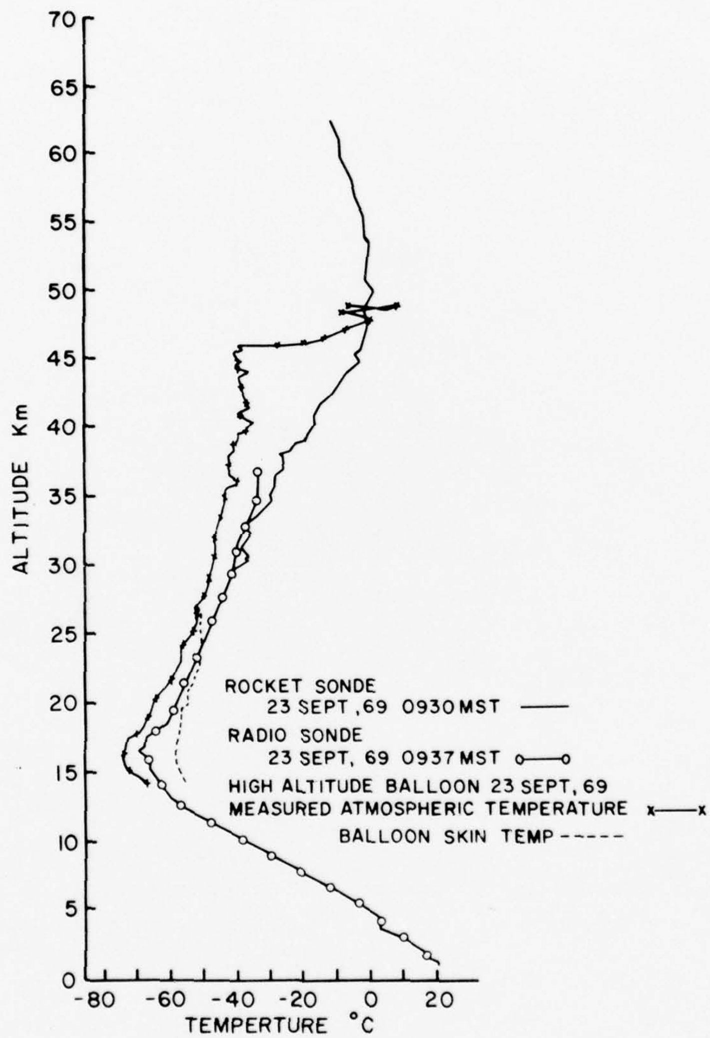


Figure 6. Rocketsonde, radiosonde and balloon-borne (STRATCOM II) temperature sensor measurements - September 1969.

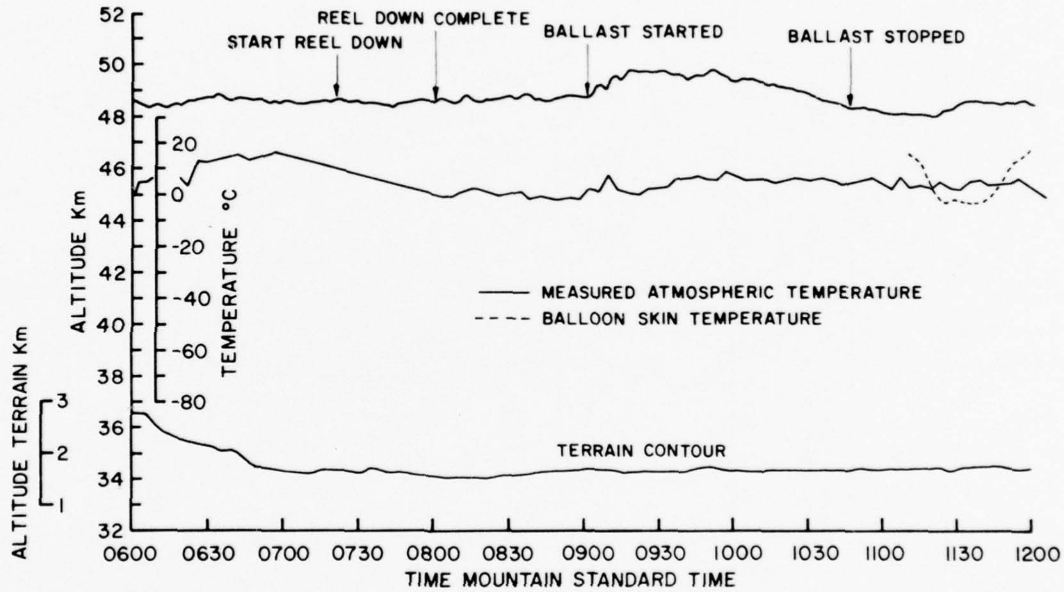


Figure 7. STRATCOM II balloon altitude and atmospheric temperature as functions of time (0600-1200) - September 1969.

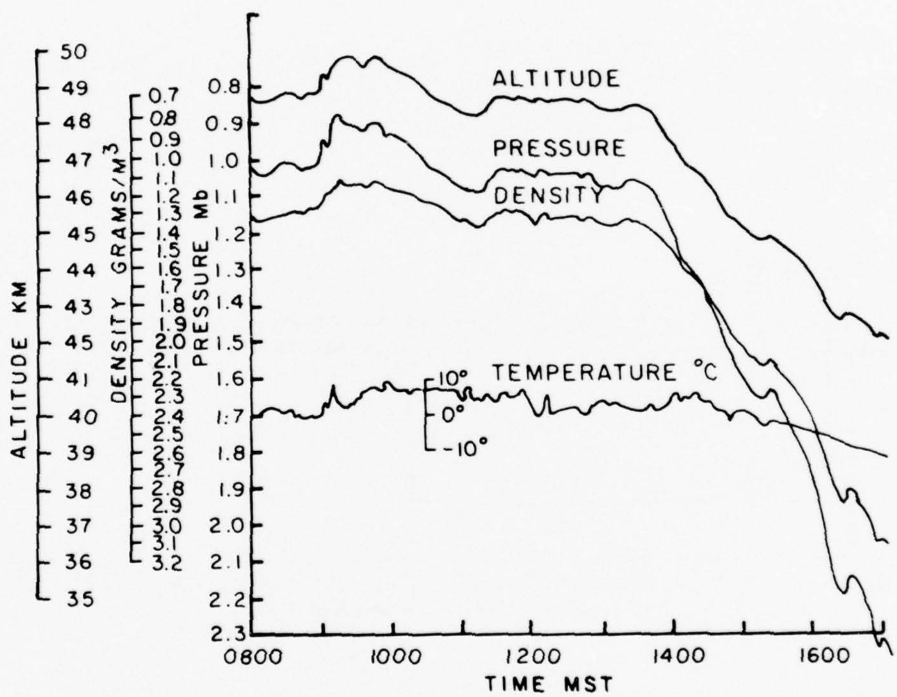


Figure 8. STRATCOM II balloon altitude and atmospheric pressure, density, and temperature as functions of time (0800-1600) - September 1969.

time of sunrise at the balloon altitude, the effect of the now warmer-than-atmosphere balloon on the indicated atmospheric temperature. It is particularly well illustrated between 0700 and 0800 when the sensing payload was lowered to a distance of 320 m beneath the balloon. Here the indicated temperature decreased from +19°C to 0°C with the balloon altitude remaining constant at 48.7 km during, and somewhat after, the time of payload reel-down. It is also indicated immediately after 0900 when, due to ballast release, the balloon altitude increased from 48.7 to 50.0 km. The temperature sensor 320 m beneath the balloon was pulled into the wake of the warmer-than-atmosphere balloon by the 1.3 km increase in altitude. This is evidenced by an apparent increase in atmospheric temperature of +10°C. The indicated air temperature then decreased to +1°C when the balloon was floating stably at 50 km.

Between 0920 and 0930 (Figure 7) the balloon was floating at an altitude of 50 km. The air temperatures registered by the balloon-borne sensor at these times were +1°C and +3°C, with the balloon having traversed a horizontal distance of approximately 5 km in this 10-minute interval. The temperature registered by the identical 0930 MST rocketsonde sensor, at an altitude of 50 km (Figure 6) but at a space point approximately 100 km from the balloon-borne sensor, was 0°C.

Figure 8 presents, somewhat compressed in time, the balloon altitude and measured temperatures at points 320 m beneath the lower end of the balloon in the period 0800-1700 MST. To determine the magnitude of the diurnal temperature variation, a constant altitude line at 48.7 km was drawn on the balloon altitude versus time data between 0800 when the instrument package reel-down was complete and 1330 when the balloon began its monotonic descent. This established that the balloon was at 48.7 km (±100 m) at 0800-0900, 1040, and 1130-1330. Between 0800-0900, the measured atmospheric temperature was slightly variable at 0°C; at 1040, 1130, and 1150, it was +7°C.

To this point, the magnitude of the diurnal temperature variation would appear to have been indicated. Unfortunately, between 1150 and 1205 the indicated air temperature decreased from +7°C to -2°C. This decrease was followed by a sharp increase to +8°C at 1215 and a sharp decrease to 0°C at 1230. From 1230-1330 the temperature was slightly variable at +1°C.

Based upon the temperature data obtained during the STRATCOM II experiment, it was concluded that accurate measurements of atmospheric temperature could be obtained from instruments supported by large balloons provided provisions were made for an adequate separation between the temperature sensor and the balloon above it. In this case, a distance of 320 m was sufficient, relative to a balloon having a diameter of 127 m. In addition it was established that erroneous atmospheric temperature would be registered by the temperature sensors below the balloon, if the sensors were following upward in the balloon wake and the

balloon was at a temperature different from that of the atmosphere. This conclusion was possible through having a knowledge of the balloon skin temperature.

It was noted that during the time period of this experiment the atmospheric horizontal temperature variability at 48.7 km was quite large with a maximum horizontal temperature gradient of 1°C/km being observed. This variability was particularly evident when the balloon was in the proximity or over mountainous terrain on the earth's surface.

Because of this horizontal temperature variability, no definite conclusion was drawn concerning the magnitude of the diurnal temperature variation to be associated with the thermal tide; however, it was established that there was a temperature increase in the tidally driven air parcel at 48.7 km of +7°C between 0800 and 1150 MST when the balloon was first moved southward and then northward over identical nonmountainous terrain (Figure 5).

STRATCOM III Experiment Description [3]

Funding difficulties and management policies prevented the continuation of the STRATCOM balloon-borne experiments in 1970 and 1971; however, by 1972 these problems had dissolved and balloon technology deemed it feasible to launch a sensing payload of 250 pounds to an altitude of 50 km. Thus, a cooperative experiment was conducted in 1972 by ASL, AFGL, SLA, with contract support from UTEP, the Ionospheric Research Laboratory of Pennsylvania State University, Panametrics, Inc., and Winzen Industries, Inc.

A 38 million cubic foot, zero-pressure, polyethylene balloon was launched from Holloman AFB on 18 September 1972 at 0304 MST. It carried to a peak altitude of 48.7 km an atmospheric parameter sensing payload of 250 pounds consisting of uv filter photometer, cryogenically pumped mass spectrometer, atmospheric sampler, pressure gages, cosmic ray detector and aluminum oxide water vapor sensors. Film-mounted spherical bead thermistors again served as the temperature sensors.

In addition, magnetometer, pendulum and temperature sensors were utilized to determine the orientation and instrument frame temperature of the principal payload, which was reeled downward a distance of 1200 feet (390 m) beneath the balloon as the balloon passed its 23 km altitude.

A secondary payload consisting of aluminum oxide water vapor sensor and balloon-skin temperature sensor was mounted on the apex plate at the top of the balloon.

Figure 9 is a photograph of the principal payload just before it was launched. Figure 10 is a photograph of the payload at the top of the balloon, and Figure 11 shows the balloon and principal payload at its

float altitude near 48.5 km with the payload suspended 390 m beneath the balloon. The vertical and horizontal component trajectories are shown in Figures 12 and 13, respectively.

The objectives of the experiment were to measure the detailed time and space variations (40-50 km) in atmospheric composition and the related variations in the meteorological parameters of temperature, pressure, and density at times of darkness, sunrise and daylight, the sunrise and daylight variations to be related to the measured uv solar flux. Implicit in these objectives was the determination of the diurnal tidal temperature variation.

STRATCOM III Temperature Measurements [4]

In Figure 9, of the seven cylindrical rods extending below the top of the vehicle in the photograph background, counting from left to right, rods three and six served as mountings for the temperature sensors.

Although film-mounted bead thermistor sensors had been mounted in a two-thermistor configuration for the STRATCOM I and II experiments to have redundant measurements, no attempt had been made to determine the atmospheric temperature from the temperature records except during the times the thermistors and their mountings were completely shielded from direct solar radiation. For mid-September this total shielding, for the thermistor configuration utilized, begins at 0800 MST at an altitude of 50 km over WSMR and persists until approximately 1600 MST.

To overcome this difficulty on the STRATCOM III flight, the thermistors and their thin-film mountings were arranged as shown in Figure 14. The figure shows the orientation of the film mounts relative to one another as they were suspended on the balloon-borne instrument platform. When solar radiation was incident in a direction which was perpendicular to the plane of one film, then the direction of the incident solar rays was parallel to the second film. The argument was that if the payload platform rotated during the balloon flight, at some time the above condition of perpendicular and parallel incident rays relative to the two film surfaces would exist and the maximum difference in temperatures recorded at that time by the two identical sensors would be an experimental determination of the maximum solar radiation correction to the temperatures recorded by the film-mounted thermistors.

Figure 15 (a and b) is an expanded-in-time section of the temperature record obtained during the flight between 0559 and 0607 MST on 18 September 1972. Figure 16b is the time-shared record of Figure 15a with the dashed times indicating the temperatures that were being sensed by thermistors B_1 and B_2 in the time intervals when their data were not recorded. Reference to Figure 14 (as related to Figure 15b) concerning the relative orientation of the thermistor film mounts indicates that the plane of film B_1 was perpendicular to the direction of incident solar radiation at 0604 while the plane of film B_2 was parallel to this direction. At approximately 0604 the maximum difference of 12°C between the

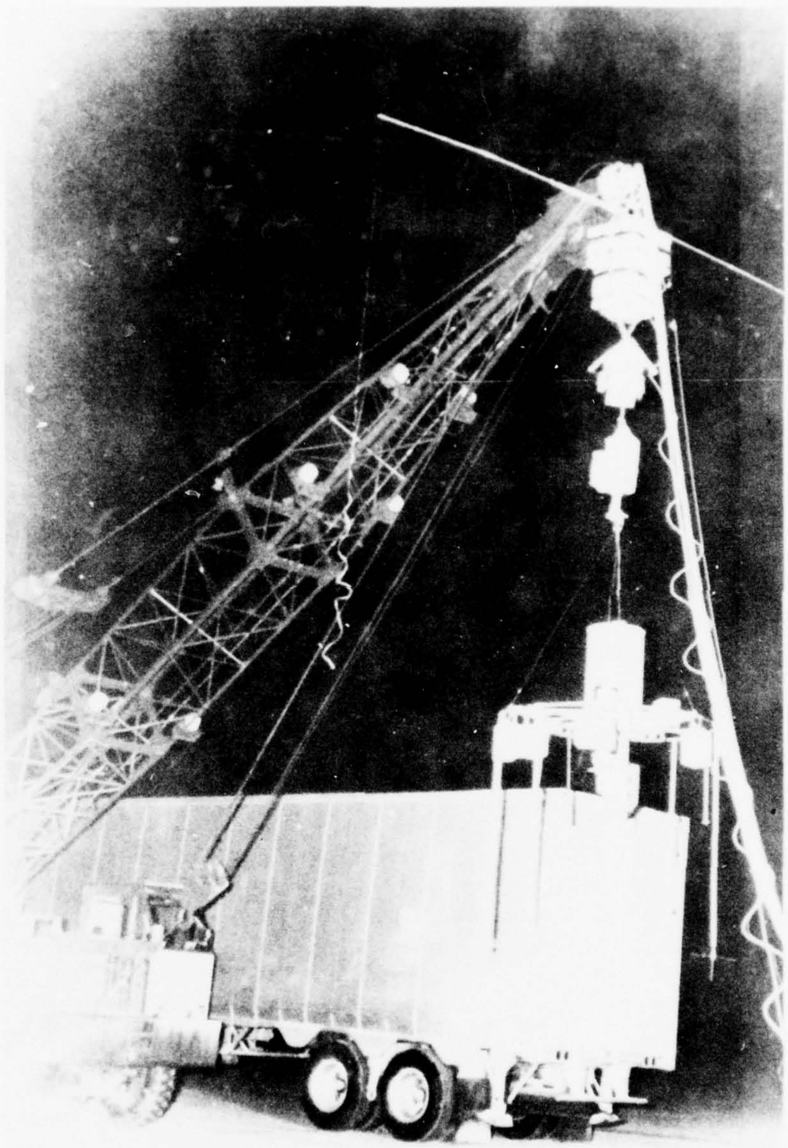


Figure 9. STRATCOM III principal payload - September 1972.

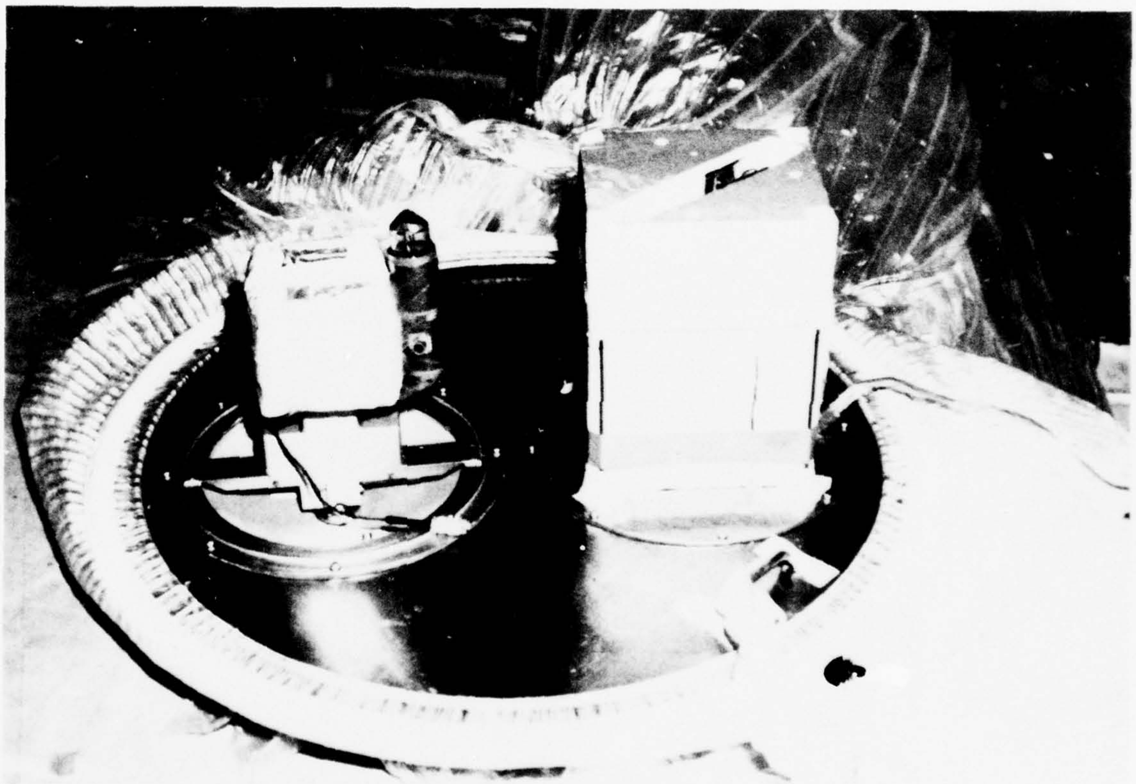


Figure 10. STRATCOM III payload on apex plate of balloon - September 1972.

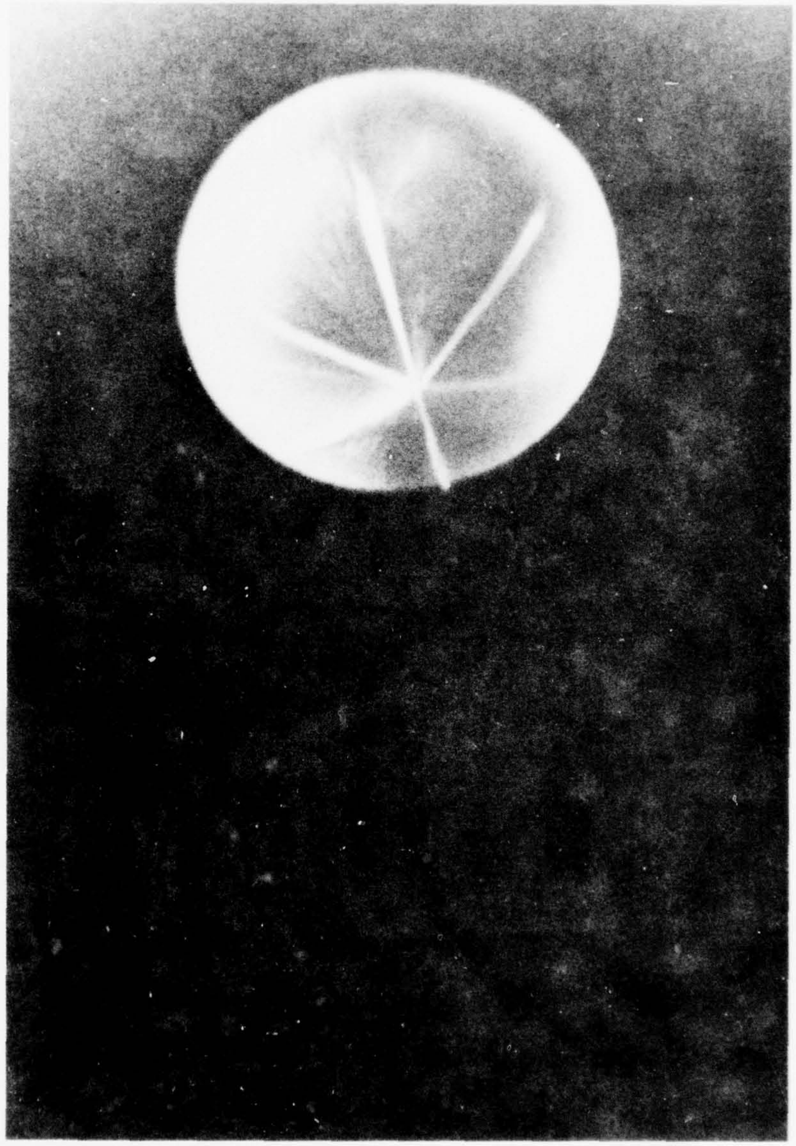


Figure 11. STRATCOM III balloon at float altitude - September 1972. Payload 1200 ft beneath balloon (not visible in photograph reproduction).

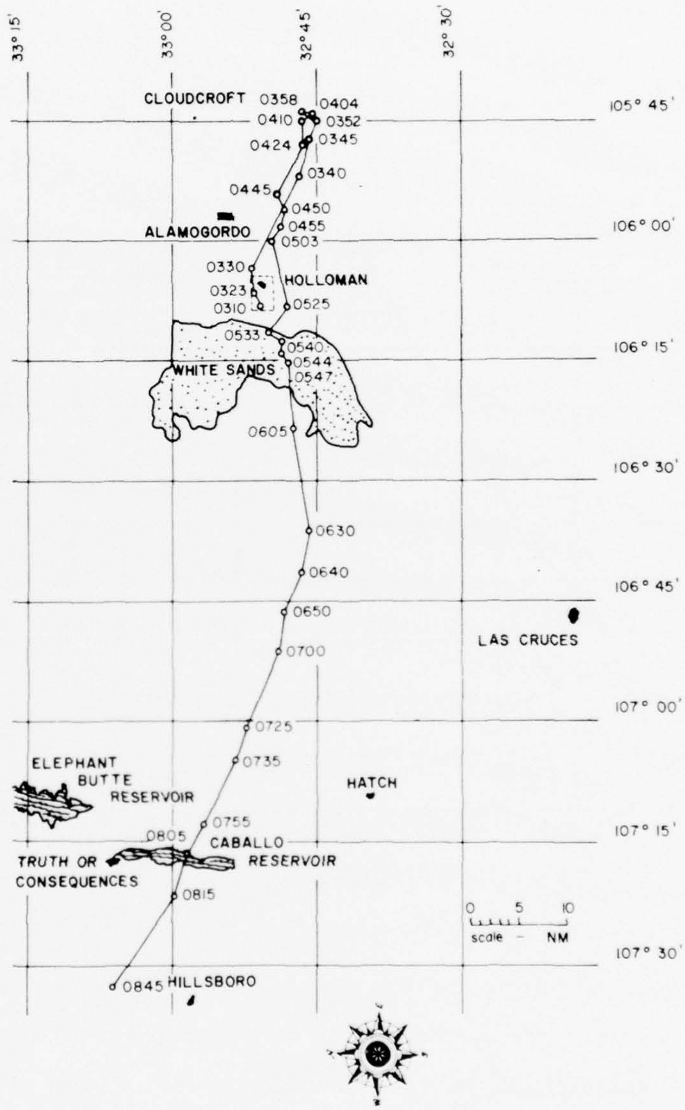


Figure 12. STRATCOM III balloon horizontal trajectory - September 1972.

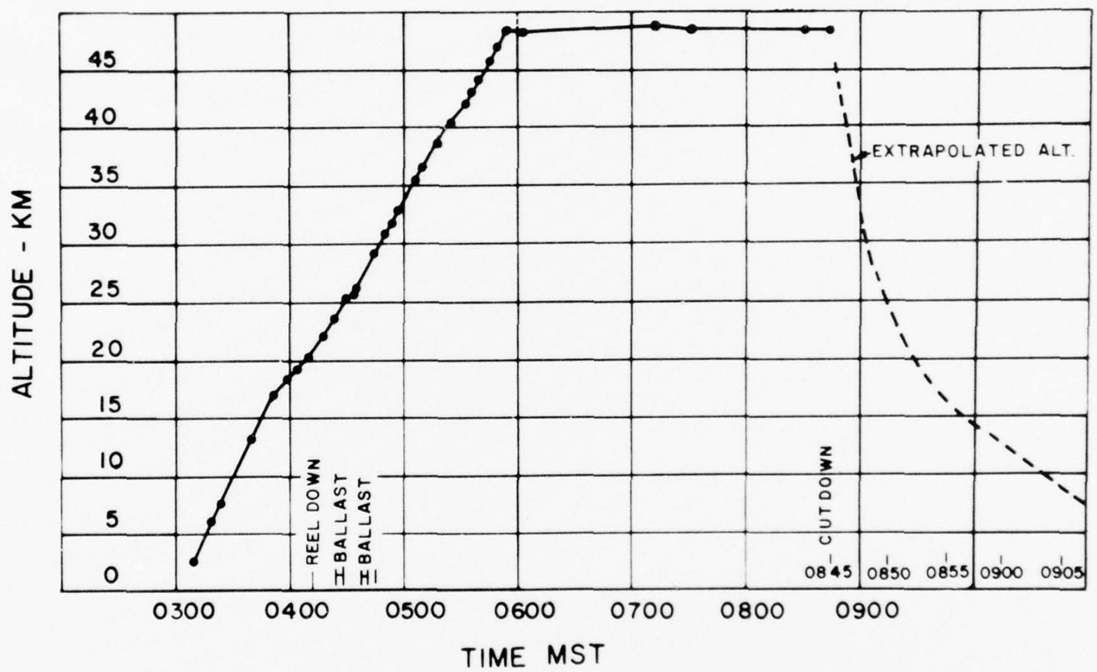


Figure 13. STRATCOM III balloon altitude vs time - September 1972.

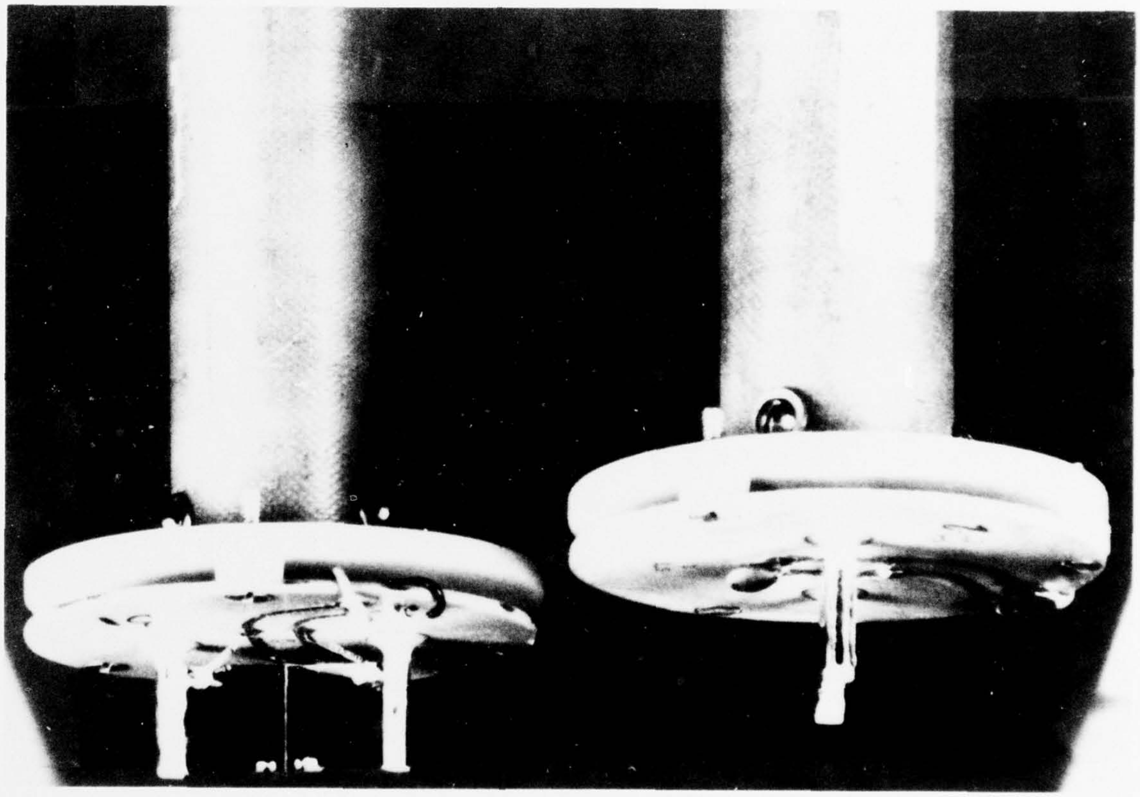


Figure 14. STRATCOM III film-mounted spherical bead thermistor configuration - September 1972.

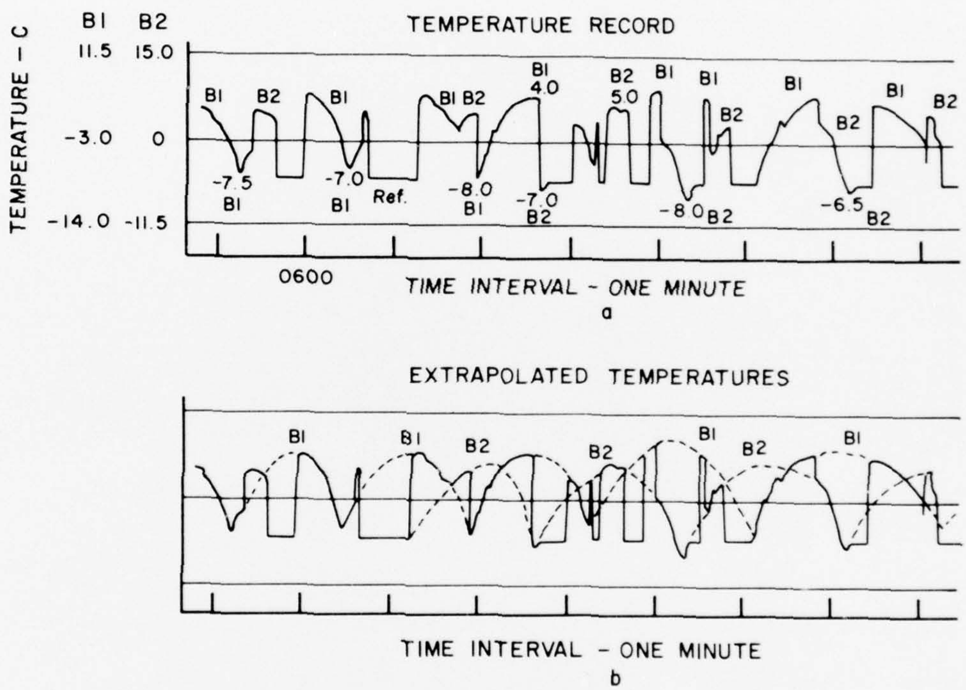


Figure 15 (a-b). STRATCOM III temperature record (0559-0607) - September 1972.

temperatures recorded by sensors B_1 and B_2 occurred, implying that the solar elevation angle at 48 km (the altitude of the thermistor sensors) was zero degrees at 0604 and that 12°C was the maximum solar radiation correction to the temperatures recorded by either one of the sensors at that altitude. Figure 15b also shows that the rotation period of the sensors on the principal payloads was 3 minutes and 48 seconds at times near 0604. The rotation of the principal payload relative to the earth's magnetic field, as determined by the onboard magnetometer, was also 3 minutes 48 seconds during this time. The planes of the thermistor film mounts were established to be vertical from the payload pendulum data.

Thus, the shape of the continuous temperature records for sensors B_1 and B_2 gives the orientation of the two sensor mounts relative to the direction of incident solar radiations. Minimum points on the temperature traces indicate the times the solar radiation correction is zero, with the recorded temperature representing the actual air temperature (all other corrections being negligible). This, coupled with the aforementioned complete shading of the sensors from direct solar radiation, permits the accurate determination of atmospheric temperature through all phases of the flight without having to resort to theoretical corrections to the observed temperatures. The experimental considerations summarized briefly here, as well as the theoretical calculations of heat transfer related to them, are presented in detail in the above-referenced publications concerning the STRATCOM III experiment.

Specifically, an examination of the photographs of the film-mounted thermistors (Figure 14) shows that sensors B_1 and B_2 both became totally shaded from directly incident solar radiation when the solar zenith angle exceeded +27 degrees. A zenith angle of +27 degrees occurred at an altitude of 48 km on 18 September 1972 over WSMR at 0757; thus, the temperatures recorded by both sensors were independent of directly incident solar radiation after 0757.

Figure 16 presents the directly recorded temperatures from sensors B_1 and B_2 from balloon launching at 0304 MST to loss of signal at 0905 MST ($\sim$15 km) from the principal payload which was floating downward on a parachute after flight termination at 0845 MST. Also depicted in the figure is the balloon-skin temperature as a function of time as measured by the thermistor attached to the balloon surface near the top of the balloon.

From the considerations discussed above, as related to temperature sensor orientation toward, and shielding from, directly incident solar radiation, Figure 17 presents the atmospheric temperature versus time data derived from the data of Figure 16. The figure shows that while the balloon was floating stably near 48.5 km, with the temperature sensors near 48.1 km, the air temperature was -7.0°C at 0600, -4.0°C at 0700, -3.0°C at 0800, -1.5°C at 0815, +1.0°C at 0830, and 0.0°C at 0845. The total atmospheric temperature change from 0600 to 0845 MST, at an altitude of 48.1 km would thus be approximately +7°C, with all

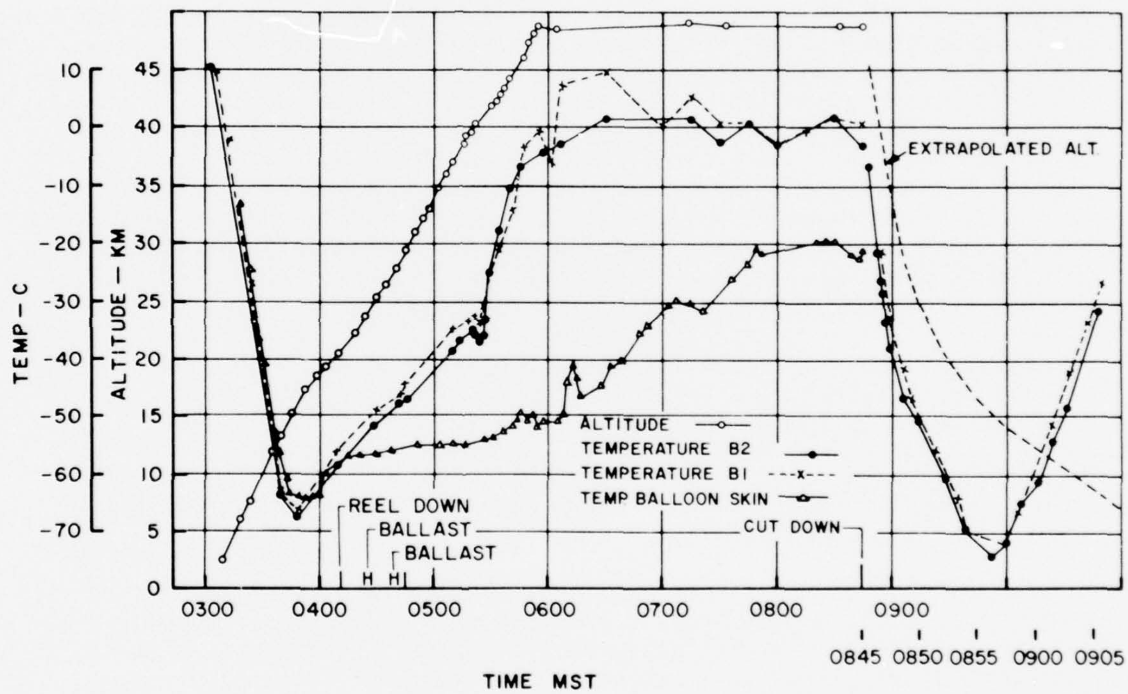


Figure 16. STRATCOM III atmospheric and balloon skin temperatures as functions of time - September 1972.

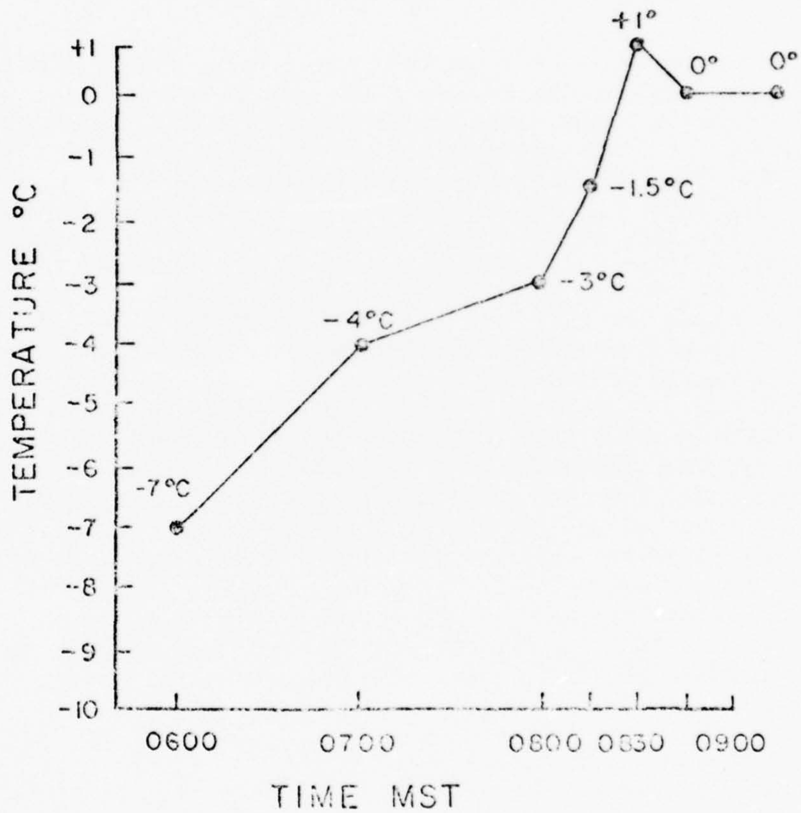


Figure 17. Change in temperature at 48.1 km (0600-0845 MST) - 18 September 1972, STRATCOM III.

stated temperatures calculated to be correct within ±1°C. The balloon-borne temperature sensor determination of the temperature change of +7°C occurred during the STRATCOM III experiment within a period of approximately 3 hours in an air parcel at 48 km that was transporting the balloon. This occurrence again implies at least partial agreement with the rocket-borne sensor determination of a temperature change of +15°C (minimum to maximum) occurring within a 24-hour period in an air parcel at 50 km [5,6].

STRATCOM IV Experiment Description

In early 1973, Bell Laboratories, through their relationship with SLA, became associated with the STRATCOM program. On 20 October 1973, after 10 months of intensive preparation by personnel from Bell Laboratories and personnel from the same organizations listed above as participating in the STRATCOM III experiment, the STRATCOM IV balloon-borne experiment was launched from the National Center for Atmospheric Research (NCAR), Balloon Facility at Palestine, Texas (32° N, 97° W), at 0348 CST aboard a 6.7 million cubic foot balloon. The balloon and instrument system, helium, parachute, rigging and ballast gave a total system weight of 8868 pounds for this fourth experiment in the STRATCOM series. The payload, which was suspended immediately beneath the balloon after launching, is shown in Figure 18.

A study of Figure 18 shows that this principal payload was fabricated as a two-tier system. The upper tier consisted of the same instruments, arranged in generally the same configuration as for the STRATCOM III flight. This portion of the payload again weighed approximately 250 pounds. The opto-acoustic laser system of Bell Laboratories formed the lower tier of the payload. The laser system weighed approximately 4800 pounds, giving a total payload weight beneath the balloon of approximately 5000 pounds, and thus prohibiting further separation of the payload from the balloon on a reel-down mechanism after the time of the balloon launching.

A secondary payload was positioned on the apex plate of the balloon. It consisted of two thermistor sensors for the determination of balloon-skin temperature, a thermistor atmospheric temperature sensor, and an aluminum oxide water vapor sensor.

After the balloon was launched, it ascended at an average rate of 790 feet/minute and reached its maximum altitude of 28 km at 0558 CST. It is believed to have floated near this altitude for the duration of the flight, with balloon flight termination occurring at 2015 CDT over Geiger, Alabama; the balloon thus followed a horizontal trajectory such that at the time of flight termination, the balloon and instrument package were 480 miles east of the launch site.

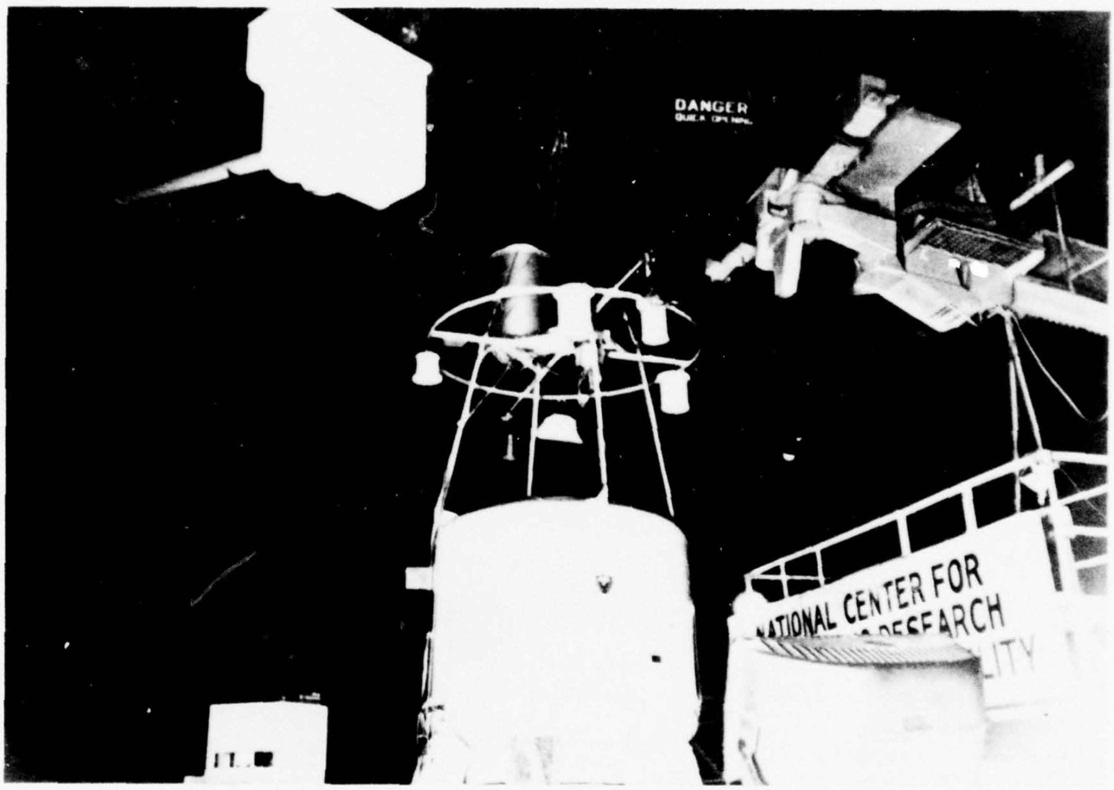


Figure 18. STRATCOM IV principal payload - October 1973.

STRATCOM IV Temperature Measurements

Since some difficulty was anticipated in attempting to measure the ambient atmospheric temperature in the presence of the massive steel housing of the opto-acoustic laser, two groups of film-mounted thermistors (two sensors in each group) were mounted in the same configuration as shown in Figure 14 for the STRATCOM III experiment. Figure 18 shows the location of the two groups of thermistor sensors. One group was suspended from the circular ring above the laser system housing, while the second identical group was reeled downward to slightly below the laser system when the balloon and payload passed through the 3 km altitude during ascent.

Figure 19 presents the balloon altitude, reeled-down sensor temperature T_r, platform sensor temperature T_p, and the balloon-skin temperature T_s as functions of time, from balloon launching at 0348 CST to loss of the transmitted signal from the payloads at 1600 CST. The payload was suspended by a parachute approximately 100 feet beneath the 150-foot diameter balloon, and no radar or pressure-altitude data were available. The constant balloon altitude indicated in Figure 19 is highly approximate. A detailed analysis of the corresponding temperature records, with sensor locations considered, indicates when the vertical motions of the balloon were sufficient to produce large changes in the recorded temperatures, the changes produced by the motion of the sensors into and out of the wake of the relatively large and massive metal payload which was at a temperature much higher than the temperature of the balloon and the ambient atmosphere.

In summary, the erratic nature of the recorded temperatures shows the perturbations produced in the ambient atmospheric temperature near 28 km by the proximity of the sensors to large balloon and massive payload. No new useful information was gained from the STRATCOM IV experiment concerning the temperature structure of the stratosphere and its variation.

STRATCOM V Experiment Description

The fifth in the series of STRATCOM payloads was launched on 22 May 1974 on a 6.7 million cubic foot balloon from Holloman AFB, New Mexico. This experiment was again a cooperative research effort conducted jointly among ASL, SLA, the Aerospace Instrumentation Division of AFGL, with contract support from UTEP and Panametrics, Inc., of Waltham, Massachusetts, and Winzen Industries, Inc. Also participating were the Ionosphere Research Laboratory of Pennsylvania State University, the Meteorological Branch of the Air Force Weapons Laboratories, Kirtland Air Force Base, New Mexico, and Bell Telephone Laboratories.

After launching at 0122 MST, the balloon reached an altitude of 24 km at 0437 MST, the time of sunrise at that altitude. After sunrise, it rose to its designed float altitude of 28 km at 0526 MST. It slowly descended throughout the day, reaching 22.4 km at 1934 MST, the time of sunset at that altitude.

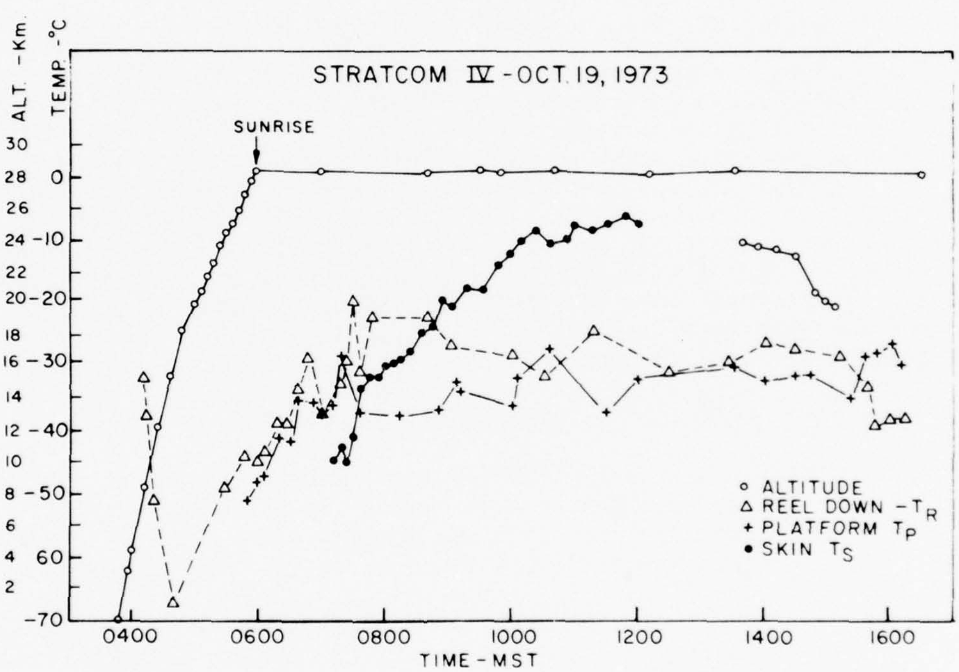


Figure 19. STRATCOM IV balloon altitude and temperature T_R, T_P and T_S as functions of time - October 1973.

After sunset, the balloon continued to slowly descend. The decision was made to terminate the balloon flight at 0050, 23 May, with the balloon and payload reaching the earth's surface on WSMR. Approximately 22 hours of telemetered data were recorded by receiving stations at WSMR, Holloman AFB, and Globe, Arizona. Figure 20 shows the horizontal and vertical components of the balloon and payload trajectory.

The objective of the STRATCOM V experiment was to determine simultaneously the incident solar uv radiation, atmospheric composition, atmospheric thermal flow and charged particle structure, cosmic radiation levels, and aerosol layers as they varied in time and space. To accomplish this objective, the atmospheric sensing payload consisted of uv spectrometer, water vapor, ozone and nitric oxide sensors, bead thermistor temperature sensors, cameras to photograph falling chaff and small spheres, three component anemometers for the determination of airflow relative to the balloon, radar reflector for the determination of windspeeds from the radar track of the balloon, atmospheric turbulence sensor, positive ion and Gerdien condensor probes, cosmic ray sensor, and cameras to photograph aerosol layers. The combined atmospheric parameter sensing payload and balloon control package resulted in an instrument weight of 6300 pounds. Figure 21 shows the principal payload beneath the balloon. An instrument package on the apex plate of the balloon was used to determine and telemeter to ground-based receivers the balloon-skin temperature.

STRATCOM V Temperature Measurements

The configurations of the STRATCOM IV and STRATCOM V payloads are very similar. As in the STRATCOM IV experiment, the opto-acoustic laser system of Bell Laboratories, which was housed in the modified massive metal shell shown in Figure 21 and tuned to measure stratospheric nitric oxide and ozone concentrations, accounted for most of the 6300 pounds of payload weight beneath the balloon. The weight of this magnitude again precluded reel-down of the instrument package from the balloon so as to minimize the thermal and composition contamination of the atmospheric region in which the sensors were located.

Since difficulty was anticipated with this configuration in measuring the ambient atmospheric temperature, two coupled pairs of film-mounted spherical bead thermistors were mounted, as for STRATCOM IV, on the principal payload. One pair was mounted permanently on the circular ring shown in Figure 21, while the other pair was mounted on the circular ring in a configuration which permitted reel-down of the temperature sensors after the balloon and payload were launched. In this case, the temperature sensors extended approximately 15 feet below the lower extremity of the principal payload after reel-down.

Figure 22 presents the altitude of the payload and the corresponding temperatures T_r, T_p, and T_s recorded by the reeled-down sensor, platform sensor, and balloon-skin sensor, respectively, all as functions of time.

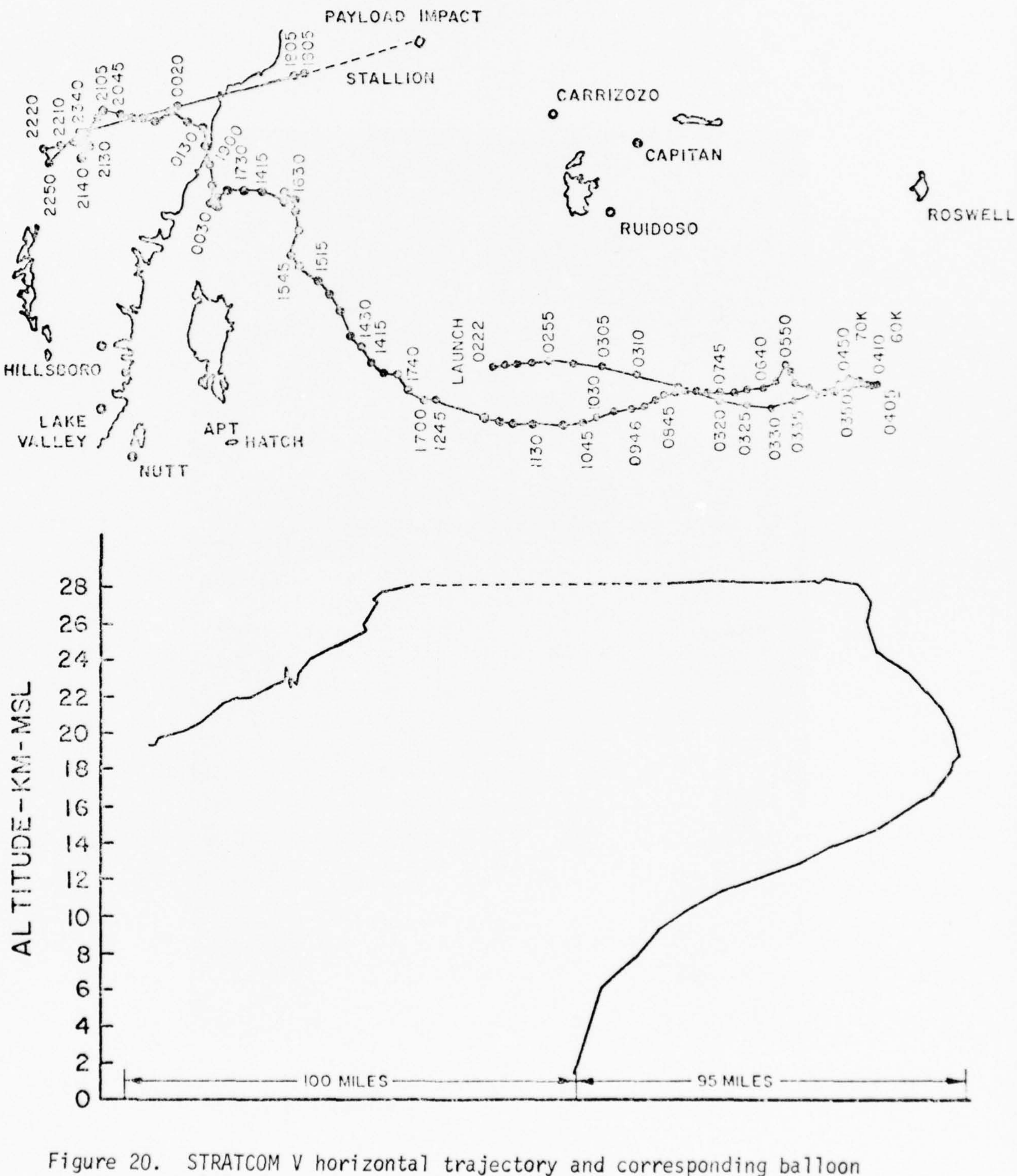


Figure 20. STRATCOM V horizontal trajectory and corresponding balloon altitude vs distance from point of launching - May 1974.

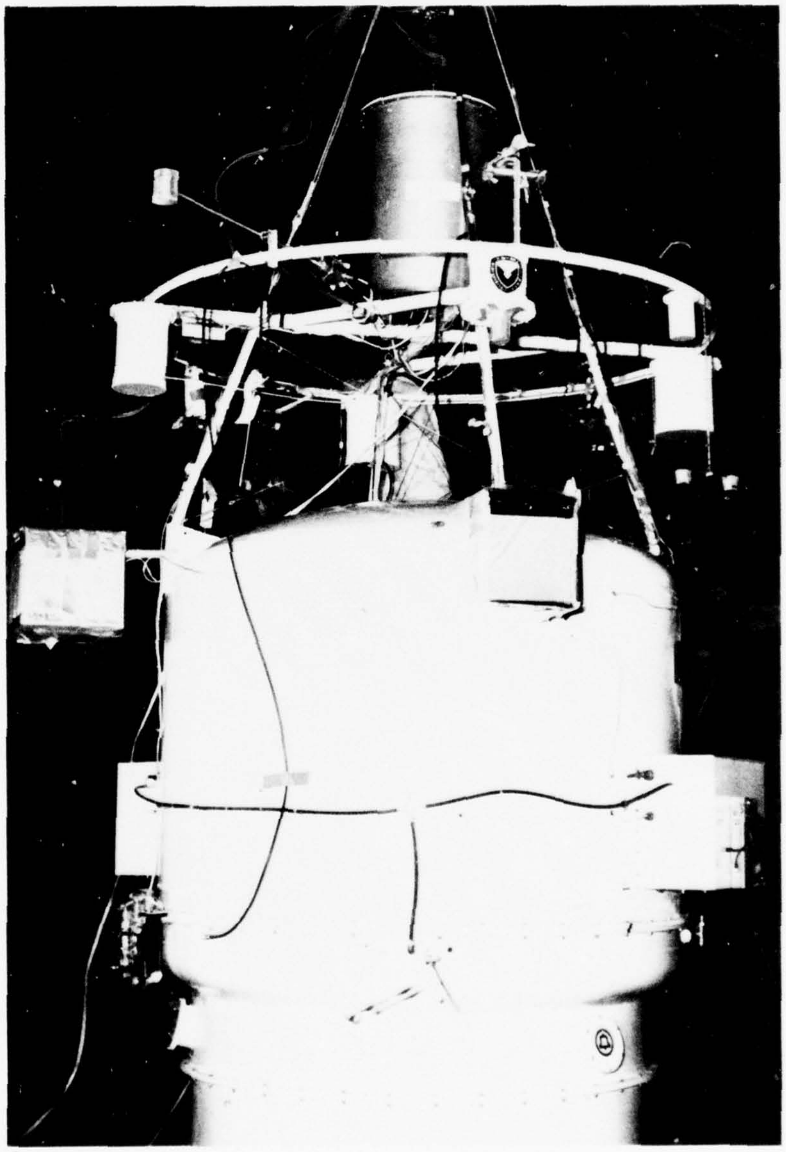


Figure 21. STRATCOM V principal payload - May 1974.

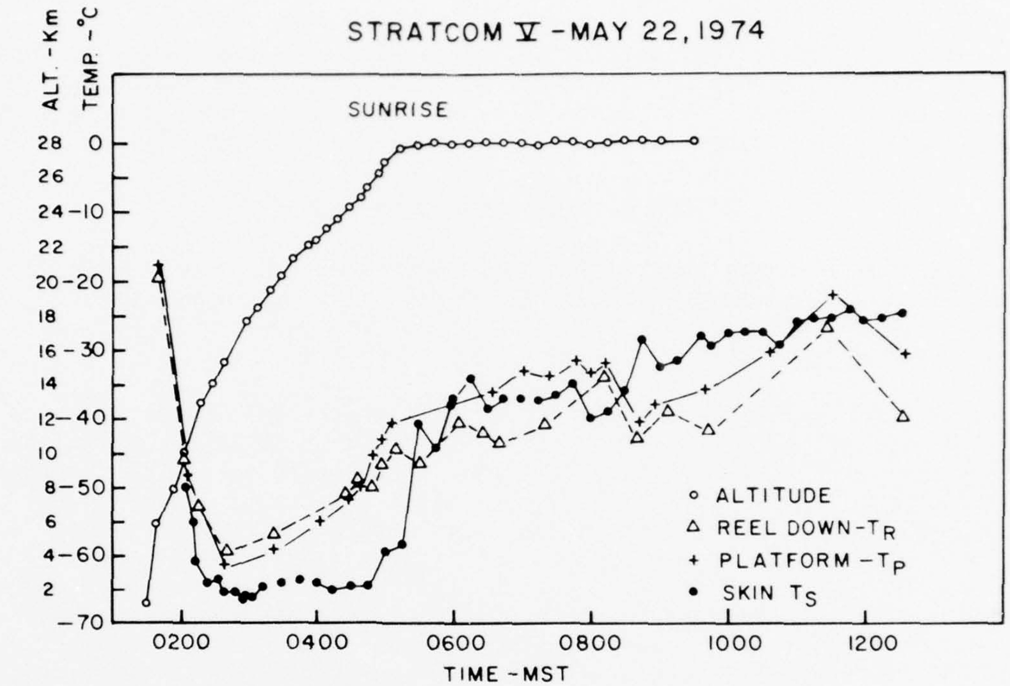


Figure 22a. STRATCOM V balloon altitude and temperature T_r, T_p, and T_s as functions of time (0200-1200) - May 1974.

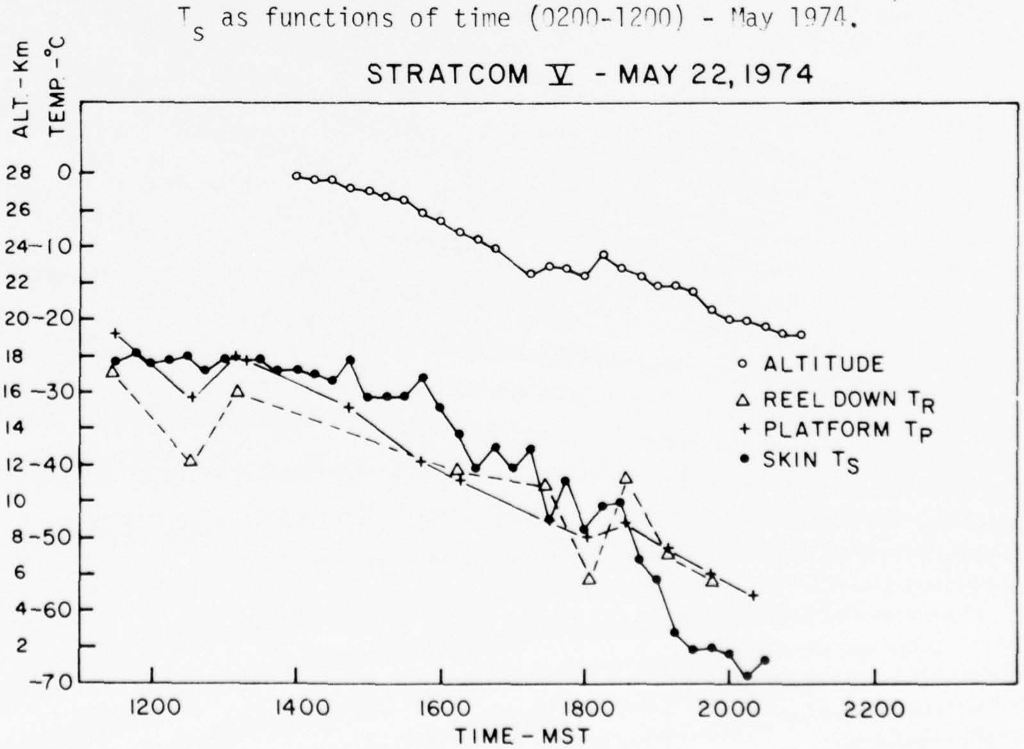


Figure 22b. STRATCOM V balloon altitude and temperature T_r, T_p, and T_s as functions of time - (1200-2200) - May 1974.

No additional useful information was gained from the experiment concerning the actual temperature structure of this atmospheric region and its variation with time. This again is attributed to the close proximity of the temperature sensors to the massive payload and large balloon.

STRATCOM VI Experiment Description

The STRATCOM VI-b payload, lifted on 26 September by a 2.9 million cubic foot balloon to an altitude of 30 km, was used to measure the concentrations of $CFCL_3$ and CF_2CL_2 in the stratosphere. The results of the experiment have been reported elsewhere [7].

The STRATCOM VI-a balloon supported an atmospheric sensing payload weight of 1180 pounds consisting of 29 instruments to make simultaneous measurements of solar uv flux, atmospheric composition, and thermodynamic structure in the 27-40 km atmospheric height interval. The 15.6 million cubic foot (diameter 347 ft) balloon was launched at 2257 MST, 23 September 1975. It reached its initial float altitude of 38.5 at 0300 MST on 24 September. The various instruments were activated intermittently during ascent and then continuously for a period extending from 1 hour before to 1 hour after sunrise at 38.5 km (0529 MST). Periodic measurements were made near 38.5 km and during a slow descent which was initiated at 1100 MST. A 2-hour period of continuous measurements was conducted near 27 km through the time of sunset (1828 MST) at that altitude. Sufficient ballast was released to effect a slow ascent and the balloon reached an altitude of 36 km at 0200 MST, 25 September. It floated at 36 km until sunrise (0542 MST). The balloon and payloads then rose abruptly to 39.7 km, reaching this altitude at 0812 MST. All instruments were activated before sunrise and made continuous measurements between the altitudes of 36.0 and 39.7 km. These measurements were continued at 39.7 km until 0900 MST when the principal payload was separated from the balloon and floated downward on a parachute, reaching the earth's surface at 0935. Thus, 33 hours and 38 minutes of atmospheric data were obtained between the altitudes of 2.0 and 39.7 km during the STRATCOM VI-a experiment.

A coupled pair of film-mounted thermistors again served as the temperature sensors aboard the principal payload beneath the balloon. Figure 23 shows the payload just before the balloon was launched. The payload was reeled downward to 650 feet beneath the balloon shortly after the balloon was launched. Again, a secondary payload was attached to the apex plate of the balloon (Figure 24). Spherical bead thermistors attached to the balloon-skin measured the temperature during the flight. Figure 25 shows the horizontal trajectory of the balloon.

STRATCOM VI-a Temperature Measurements

The balloon altitude versus time, corresponding to the horizontal trajectory of Figure 25, is presented in Figure 26. The atmospheric temperature and balloon-skin temperature are also presented as functions

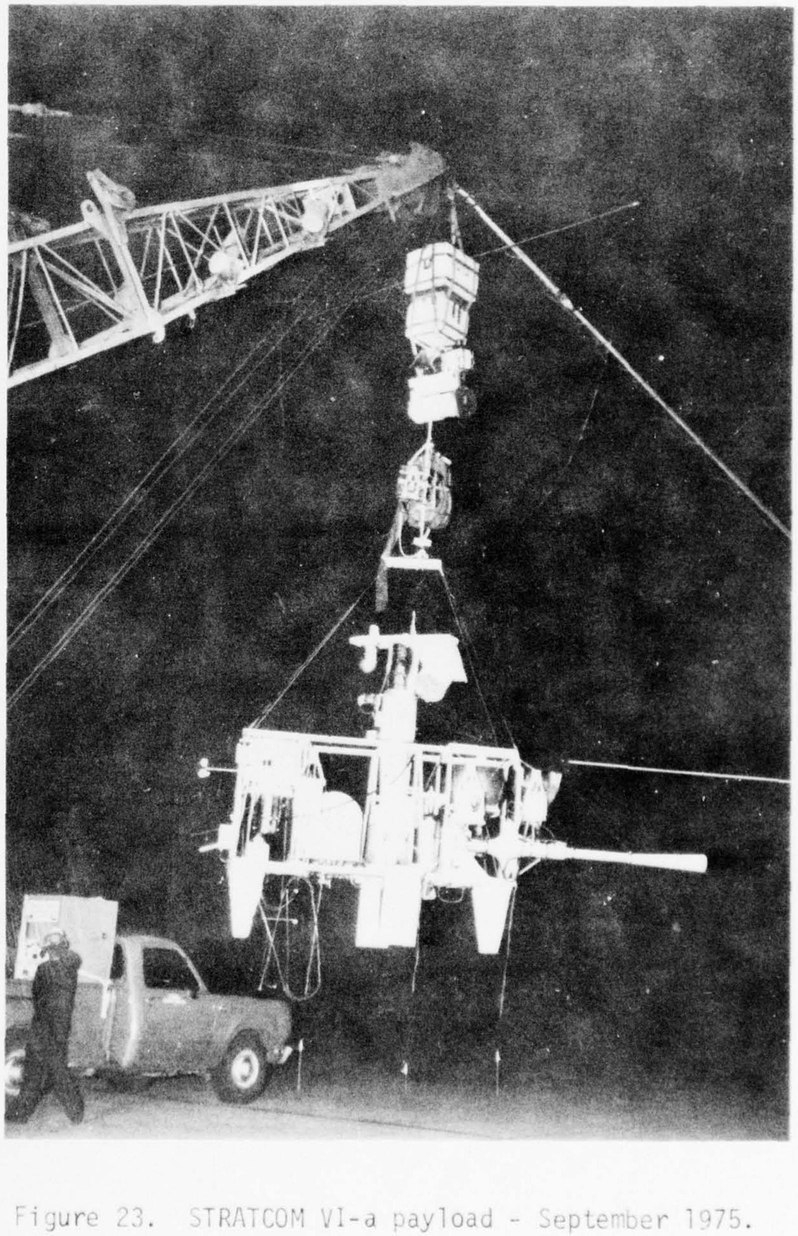


Figure 23. STRATCOM VI-a payload - September 1975.

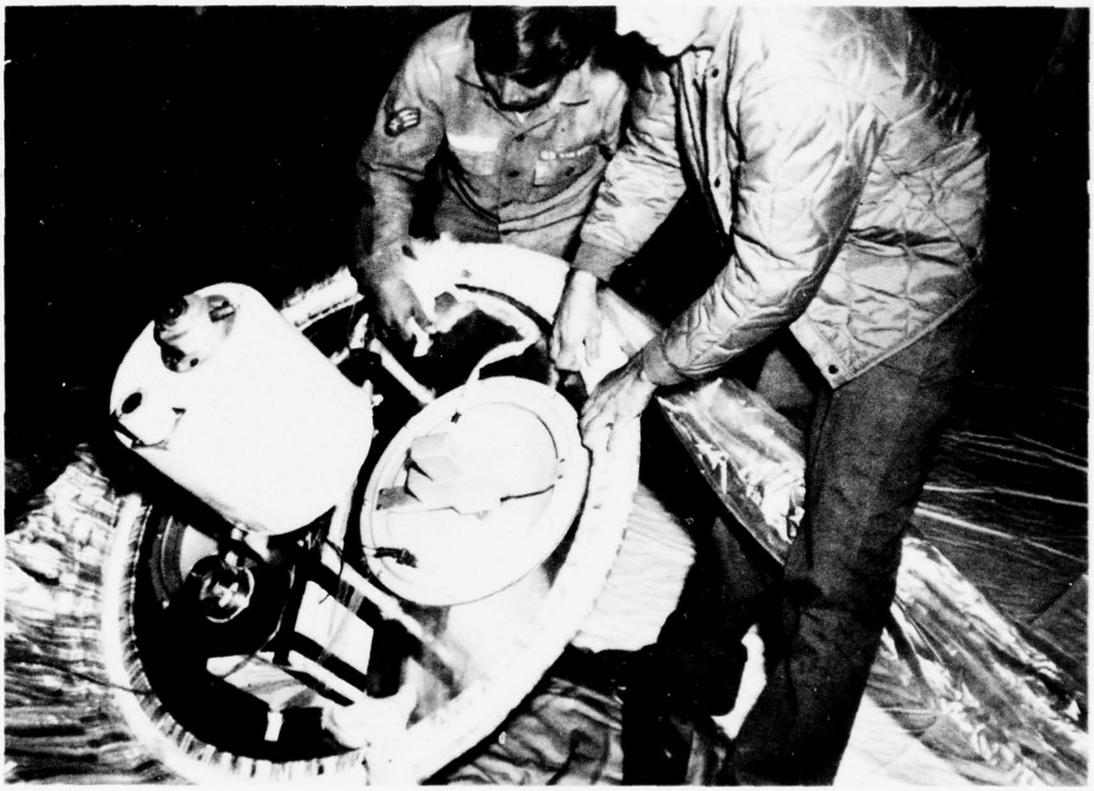


Figure 24. STRATCOM VI apex plate, mounted instrument package - September 1975.

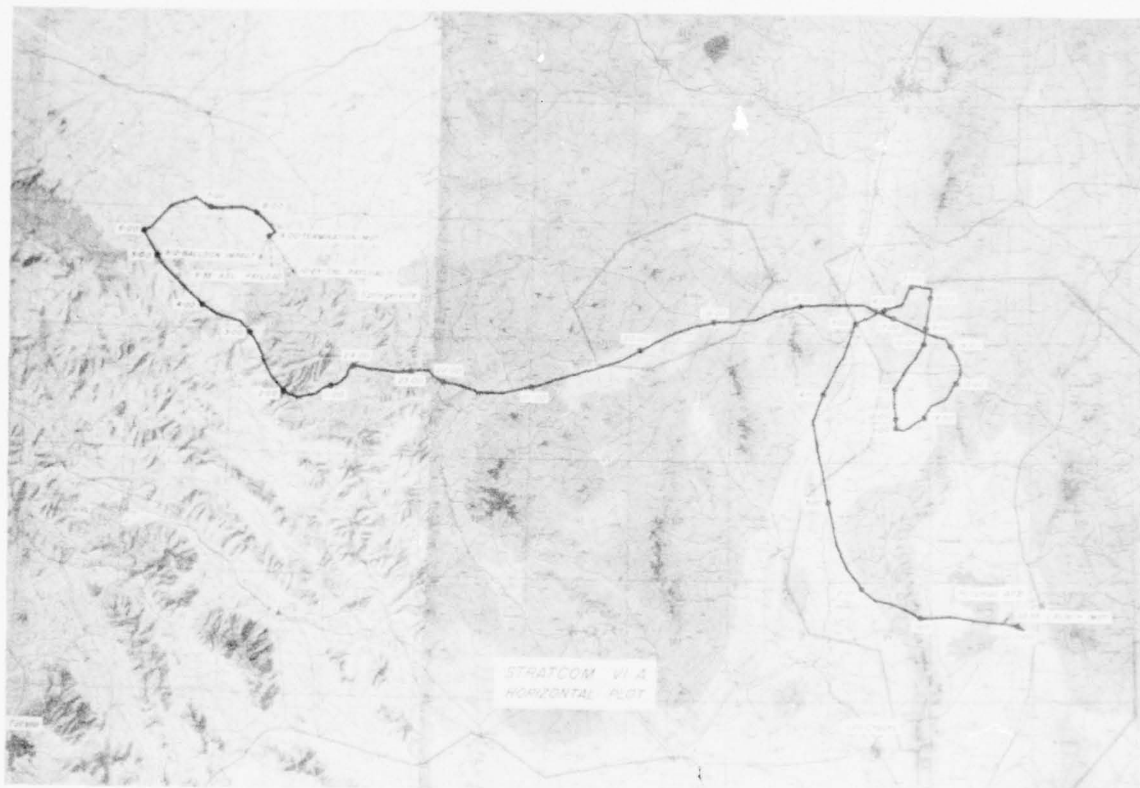


Figure 25. STRATCOM VI-a horizontal trajectory - September 1975.

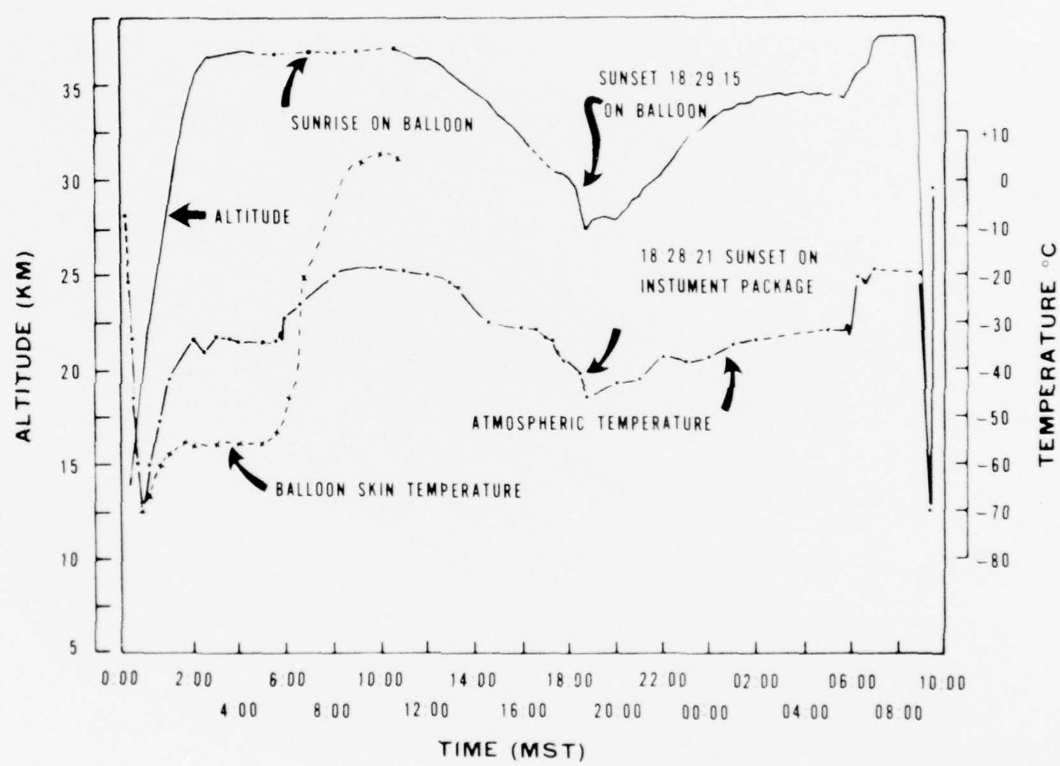


Figure 26. STRATCOM VI balloon altitude, atmospheric and balloon-skin temperatures as functions of time - September 1975.

of time. The balloon-skin temperature measurement, after 1100 MST, was not transmitted to the ground-based receiver due to depletion of battery power by the instrument on the apex plate. Excessive use of heaters at the extremely low temperature of -54°C in the period 2400 to 0600 (Figure 26) produced this instrument failure.

With the payload separated from the base of the balloon by a distance of 650 feet, many of the characteristics of the temperature records which were obtained in the 5-38 km interval (2300-0600 MST, Figure 26) are similar to the temperature versus time record of Figure 17, for the STRATCOM III experiment of September 1972. In ascending, during the night the atmospheric and balloon-skin temperature approached the tropopause temperature of -72°C (17.5 km). After passing through the tropopause, the balloon-skin temperature came to -54°C and remained near this temperature until the time of visible sunrise at the balloon altitude.

With the balloon floating at 38.5 km, the atmospheric temperature recorded by the sensors on the principal payload beneath the balloon registered -34°C at 0400 MST. After the time of sunrise, with the balloon remaining at an altitude of 38.5 km, the atmospheric temperature increased rapidly until 1100 when the sensors registered -22°C, a temperature increase of 12°C in the period 0400-1100 MST. In the same time interval, the balloon-skin temperature increased from -54°C to +5°C, becoming 24°C warmer than the surrounding atmospheric temperature.

The temperature between 1100 MST on 24 September and 0400 on 25 September, corresponding to the indicated altitude profiles of the balloon, is as represented in Figure 26.

At 0400 on 25 September, the balloon was floating at 36.0 km with an atmospheric temperature of -33°C being registered by the sensors. At 0900, with the balloon now floating at 39.7 km, the recorded air temperature had increased to -24°C. From the 1962 standard atmosphere, the temperature gradient in the 36-40 km interval is +3°C/km. The change in altitude of approximately 4 km thus precludes any conclusion concerning the temperature change at 36 km in the time interval 0400-0900 on 25 September; however, when the payload was descending on its parachute after separation from the balloon at 0900, the temperature recorded at 36 km by the film-mounted thermistor atmospheric temperature sensors suspended below the payload was -31°C. The descent rate of the parachute and payload at 36 km was 62 m/sec. The aerodynamic heating term and dissipation factor in the heat transfer equation for the film-mounted spherical bead thermistors [8] are of such values so as to give an aerodynamic heating correction to the observed temperature at 36 km of -1.5°C, while the parachute is descending at the indicated speed.

Thus, the temperature change at 36 km registered on 25 September by the temperature sensors, first floating on the balloon at 0400 and then descending in the parachute at 0900 + 1 minute, is essentially zero.

A comparison of results obtained on 24 September at 38.5 km (the change in temperature equal to +12°C in the period 0400-1200) with the results obtained at 36 km on 25 September (the change in temperature being essentially zero in the period 0400-0900) indicates that the results are not systematically repetitive on two successive days.

Identical rocketsonde temperature sensors were launched in support of the balloon experiment. Two of interest were launched at 0500 MST on 24 September and 1010 MST on 25 September. The temperature measured by the 0500 rocket-borne sensor at 38.5 km was -33.5°C, while the balloon-borne sensor measured -34.0°C at 38.5 km at 0400. A temperature of -26.0°C was measured by the 1010 rocket-borne sensor at an altitude of 40 km, while the balloon-borne sensor measured -24.0°C at 0900 at 39.7 km. The 1010 rocket-borne sensor registered -32.2°C at 36 km; while as indicated above, the temperature sensor floating downward on the parachute measured -32.5°C at 36 km. These data indicate the excellent agreement between the temperatures measured by the rocket-borne and balloon-borne sensors.

COMPARISON OF BALLOON-SKIN TEMPERATURE MEASUREMENTS

A comparison of Figure 19, which gives the balloon-skin temperature T_s as a function of time for STRATCOM IV, with Figure 22, which gives corresponding information for STRATCOM V, shows substantial differences between the temperature records of the two balloon surfaces.

As particular points for comparison, consider 1200 CST when the STRATCOM IV balloon was floating near 28 km east of Palestine, Texas, in October 1973. The balloon-skin temperature was -7°C. At 1200 MST in May 1974, with the STRATCOM V balloon floating at 28 km over WSMR, New Mexico, the balloon-skin temperature was -25°C. The atmospheric temperature in each case was approximately -40°C. The two balloons were identical in size and construction and the two payloads were identical in general configuration and dimensions.

The following data are presented as a possible argument for the differences in the balloon-skin temperatures during the two experiments:

1. The surface relative humidity at the time of balloon launching (0348 CST) at Palestine, Texas, was 95 percent with the tropopause at an altitude of 16.4 km at a temperature of approximately -70°C.

2. The surface relative humidity at the time of balloon launching (0122 MST) from Holloman AFB, New Mexico, was 16 percent with the tropopause located at an altitude of 15.2 km at a temperature of approximately -70°C.

3. At 1200 CST, the water vapor concentration, as measured by the aluminum oxide sensor on the apex plate of the STRATCOM IV balloon was variable around 1000 ppmv, while at the same time the aluminum oxide sensor on the principal payload registered 500 ppmv. It is noted here

that Patel [9] reported a measured water vapor concentration of 1.5 ppmv in the interval 1211 to 1218 CST, as determined by the Raman laser housed in the steel shell shown in Figure 18.

4. At 1200 MST, the water vapor concentration measured by the aluminum oxide sensor on the apex plate of the STRATCOM V balloon was variable around 10 ppmv. The aluminum oxide sensor on the principal payload registered values varying between 55 and 15 ppmv at this time.

5. A maximum value of 9850 ppmv occurred at 0714 CST for STRATCOM IV, while a maximum value of 500 ppmv was registered at 0700 MST for STRATCOM V.

These data indicate that the concentration of water vapor surrounding the balloon surface in the stratosphere is directly related to the concentration of water vapor at the earth's surface at the time of launching.

The total water vapor sensor record shows that the water becomes strongly attached to the balloon surface as it passes through the cold tropopause. The temperature measurements indicate that the balloon surface then remains quite cold (-55°C) until the time of sunrise, when incident radiation from the sun begins to heat the balloon surface. As the balloon surface warms, increasing quantities of water vapor are desorbed from the surface and form an envelope surrounding the balloon. The concentration in the envelope reaches a maximum value and then begins to decrease with time, the time required to reach an ambient atmospheric value dependent upon the quantity absorbed on the surface at the time of balloon release.

Thus, the argument is proposed that infrared energy radiated from the balloon surface is absorbed by an envelope of water vapor surrounding the balloon surface. The degree of absorption is related to the concentration of water vapor in the envelope. As the radiation is absorbed by the water vapor, converted to thermal energy and trapped in the water vapor envelope, the maximum temperature measured on the balloon surface is then directly related to water vapor concentration surrounding the balloon and the incident rate of deposition of solar energy.

CONCLUSIONS

The attempts to establish the amplitude of the temperature variations to be associated with the stratospheric diurnal tide, as determined by balloon-borne temperature sensors floating generally with a specific parcel of air, are not entirely conclusive; however, the results described as related to the STRATCOM II, III, and VI experiments indicate that the range of the variations to be associated with this tide within the 40-50 km altitude interval lie between 7° and 12°C and are highly variable on a day-to-day basis.

Based upon the information obtained and experience gained from the six STRATCOM experiments, it is advocated that temperature measurements be made aboard balloon-borne experiments related to the composition and charged particle structure of the stratosphere. In addition to giving background data for temperature-dependent experiments, a close examination of the records of the temperature sensors can serve as a tool for obtaining detailed information concerning the balloon and payload behavior.

REFERENCES

1. Ballard, H. N., et al., 1970, "A Constant Altitude Balloon Experiment at 48 Kilometers," J. Geophys. Res., Vol 75, No. 18, pp 3501-3512.

2. Ballard, H. N., et al., 1972, "Atmospheric Tidal Measurements at 50 km from a Constant Altitude Balloon," J. Appl. Meteorol., Vol 11, No. 7, pp 1138-1149.

3. Ballard, H. N. and F. P. Hudson, 1975, "Stratospheric Composition Balloon-Borne Experiment, 18 September 1972," Research and Development Technical Report, ECOM-5554, 111 pp.

4. Ballard, H. N., et al., 1974, "Atmospheric Temperatures Measured Near 48 Kilometers by Balloon-Borne Thermistors," Proceedings Eighth AFCRL Scientific Balloon Symposium, 30 September to 3 October 1974, pp 401-415.

5. Beyers, N. J. and B. T. Miers, 1965, "Diurnal Change in the Atmosphere Between 30 and 60 km over White Sands Missile Range," J. Atmospheric Sci., 22, 262-266.

6. Hoxit, L. R. and R. M. Henry, 1972, "Diurnal and Annual Temperature Variations on the 30-60 km Region as Indicated by Statistical Analysis of Rocketsonde Temperature Data," J. Atmospheric Sci., Vol 30, No. 5, July 1973.

7. Williams, W. J., et al., 1975, "Measurements of Stratospheric Fluorocarbon Distributions Using Infrared Techniques," Proceedings of the AGU National Fall Meeting, San Francisco, California, December 1975.

8. Ballard, H. N., and B. Rofe, 1969, "Thermistor Measurement of Temperature in the 30-65 km Atmospheric Region," Progress in Astronautics and Aeronautics, Vol 22, Academic Press, Inc., New York, 141-166.

9. Patel, C. K. N., E. G. Burkhardt, and C. A. Lambert, 1974, "Spectroscopic Measurements of Stratospheric Nitric Oxide and Water Vapor," Science, Vol. 184., 14 June 1974.

ATMOSPHERIC SCIENCES RESEARCH PAPERS

1. Lindberg, J.D., "An Improvement to a Method for Measuring the Absorption Coefficient of Atmospheric Dust and other Strongly Absorbing Powders," ECOM-5565, July 1975.
2. Avara, Elton, P., "Mesoscale Wind Shears Derived from Thermal Winds," ECOM-5566, July 1975.
3. Gomez, Richard B. and Joseph H. Pierluissi, "Incomplete Gamma Function Approximation for King's Strong-Line Transmittance Model," ECOM-5567, July 1975.
4. Blanco, A.J. and B.F. Engebos, "Ballistic Wind Weighting Functions for Tank Projectiles," ECOM-5568, August 1975.
5. Taylor, Fredrick J., Jack Smith, and Thomas H. Pries, "Crosswind Measurements through Pattern Recognition Techniques," ECOM-5569, July 1975.
6. Walters, D.L., "Crosswind Weighting Functions for Direct-Fire Projectiles," ECOM-5570, August 1975.
7. Duncan, Louis D., "An Improved Algorithm for the Iterated Minimal Information Solution for Remote Sounding of Temperature," ECOM-5571, August 1975.
8. Robbiani, Raymond L., "Tactical Field Demonstration of Mobile Weather Radar Set AN/TPS-41 at Fort Rucker, Alabama," ECOM-5572, August 1975.
9. Miers, B., G. Blackman, D. Langer, and N. Lorimier, "Analysis of SMS/GOES Film Data," ECOM-5573, September 1975.
10. Manquero, Carlos, Louis Duncan, and Rufus Bruce, "An Indication from Satellite Measurements of Atmospheric CO_2 Variability," ECOM-5574, September 1975.
11. Petracca, Carmine and James D. Lindberg, "Installation and Operation of an Atmospheric Particulate Collector," ECOM-5575, September 1975.
12. Avara, Elton P. and George Alexander, "Empirical Investigation of Three Iterative Methods for Inverting the Radiative Transfer Equation," ECOM-5576, October 1975.
13. Alexander, George D., "A Digital Data Acquisition Interface for the SMS Direct Readout Ground Station—Concept and Preliminary Design," ECOM-5577, October 1975.
14. Cantor, Israel, "Enhancement of Point Source Thermal Radiation Under Clouds in a Nonattenuating Medium," ECOM-5578, October 1975.
15. Norton, Colburn and Glenn Hoidale, "The Diurnal Variation of Mixing Height by Month over White Sands Missile Range, NM," ECOM-5579, November 1975.
16. Avara, Elton P., "On the Spectrum Analysis of Binary Data," ECOM-5580, November 1975.
17. Taylor, Fredrick J., Thomas H. Pries, and Chao-Huan Huang, "Optimal Wind Velocity Estimation," ECOM-5581, December 1975.
18. Avara, Elton P., "Some Effects of Autocorrelated and Cross-Correlated Noise on the Analysis of Variance," ECOM-5582, December 1975.
19. Gillespie, Patti S., R.L. Armstrong, and Kenneth O. White, "The Spectral Characteristics and Atmospheric CO_2 Absorption of the Ho^{+3}:YLF Laser at 2.05μm," ECOM-5583, December 1975.
20. Novlan, David J., "An Empirical Method of Forecasting Thunderstorms for the White Sands Missile Range," ECOM-5584, February 1976.
21. Avara, Elton P., "Randomization Effects in Hypothesis Testing with Autocorrelated Noise," ECOM-5585, February 1976.
22. Watkins, Wendell R., "Improvements in Long Path Absorption Cell Measurement," ECOM-5586, March 1976.

23. Thomas, Joe, George D. Alexander, and Marvin Dubbin, "SATTEL — An Army Dedicated Meteorological Telemetry System," ECOM-5587, March 1976.
24. Kennedy, Bruce W. and Delbert Bynum, "Army User Test Program for the RDT&E-XM-75 Meteorological Rocket," ECOM-5588, April 1976.
25. Barnett, Kenneth M., "A Description of the Artillery Meteorological Comparisons at White Sands Missile Range, October 1974 — December 1974 ('PASS' — Prototype Artillery [Meteorological] Subsystem)," ECOM-5589, April 1976.
26. Miller, Walter B., "Preliminary Analysis of Fall-of-Shot From Project 'PASS'," ECOM-5590, April 1976.
27. Avara, Elton P., "Error Analysis of Minimum Information and Smith's Direct Methods for Inverting the Radiative Transfer Equation," ECOM-5591, April 1976.
28. Yee, Young P., James D. Horn, and George Alexander, "Synoptic Thermal Wind Calculations from Radiosonde Observations Over the Southwestern United States," ECOM-5592, May 1976.
29. Duncan, Louis D. and Mary Ann Seagraves, "Applications of Empirical Corrections to NOAA-4 VTPR Observations," ECOM-5593, May 1976.
30. Miers, Bruce T. and Steve Weaver, "Applications of Meterological Satellite Data to Weather Sensitive Army Operations," ECOM-5594, May 1976.
31. Sharenow, Moses, "Redesign and Improvement of Balloon ML-566," ECOM-5595, June 1976.
32. Hansen, Frank V., "The Depth of the Surface Boundary Layer," ECOM-5596, June 1976.
33. Pinnick, R.G. and E.B. Stenmark, "Response Calculations for a Commercial Light-Scattering Aerosol Counter," ECOM-5597, July 1976.
34. Mason, J. and G.B. Hoidale, "Visibility as an Estimator of Infrared Transmittance," ECOM-5598, July 1976.
35. Bruce, Rufus E., Louis D. Duncan, and Joseph H. Pierluissi, "Experimental Study of the Relationship Between Radiosonde Temperatures and Radiometric-Area Temperatures," ECOM-5599, August 1976.
36. Duncan, Louis D., "Stratospheric Wind Shear Computed from Satellite Thermal Sounder Measurements," ECOM-5800, September 1976.
37. Taylor, F., P. Mohan, P. Joseph and T. Pries, "An All Digital Automated Wind Measurement System," ECOM-5801, September 1976.
38. Bruce, Charles, "Development of Spectrophones for CW and Pulsed Radiation Sources," ECOM-5802, September 1976.
39. Duncan, Louis D. and Mary Ann Seagraves, "Another Method for Estimating Clear Column Radiances," ECOM-5803, October 1976.
40. Blanco, Abel J. and Larry E. Traylor, "Artillery Meteorological Analysis of Project Pass," ECOM-5804, October 1976.
41. Miller, Walter and Bernard Engebos, "A Mathematical Structure for Refinement of Sound Ranging Estimates," ECOM-5805, November, 1976.
42. Gillespie, James B. and James D. Lindberg, "A Method to Obtain Diffuse Reflectance Measurements from 1.0 to 3.0 μm Using a Cary 17I Spectrophotometer," ECOM-5806, November 1976.
43. Rubio, Roberto and Robert O. Olsen, "A Study of the Effects of Temperature Variations on Radio Wave Absorption," ECOM-5807, November 1976.
44. Ballard, Harold N., "Temperature Measurements in the Stratosphere from Balloon-Borne Instrument Platforms, 1968-1975," ECOM-5808, December, 1976.

DISTRIBUTION LIST

Commanding Officer
Picatinny Arsenal
ATTN: SARPA-TS-S, #59
Dover, NJ 07801

Commanding Officer
Harry Diamond Laboratory
ATTN: Library
2800 Powder Mill Road
Adelphi, MD 20783

Commander
US Army Electronics Command
ATTN: DRSEL-RD-D
Fort Monmouth, NJ 07703

Naval Surface Weapons Center
Code DT 21 (Ms. Greeley)
Dahlgren, VA 22448

Air Force Weapons Laboratory
ATTN: Technical Library (SUL)
Kirtland AFB, NM 87117

Director
US Army Engr Waterways Exper Sta
ATTN: Library Branch
Vicksburg, MS 39180

Commander
US Army Electronics Command
ATTN: DRSEL-CT-D
Fort Monmouth, NJ 07703

Meteorologist in Charge
Kwajalein Missile Range
PO Box 67
APO
San Francisco, CA 96555

Environmental Protection Agency
Meteorology Laboratory
Research Triangle Park, NC 27711

Chief, Technical Services Div
DCS/Aerospace Sciences
ATTN: AWS/DNTI
Scott AFB, IL 62225

Air Force Cambridge Rsch Labs
ATTN: LCH (A. S. Carten, Jr.)
Hanscom AFB
Bedford, MA 01731

Department of the Air Force
16WS/DO
Fort Monroe, VA 23651

Director
US Army Ballistic Research Lab
ATTN: DRXBR-AM
Aberdeen Proving Ground, MD 21005

Geophysics Division
Code 3250
Pacific Missile Test Center
Point Mugu, CA 93042

National Center for Atmos Res
NCAR Library
PO Box 3000
Boulder, CO 80303

William Peterson
Research Association
Utah State University, UNC 48
Logan, UT 84322

Commander
US Army Dugway Proving Ground
ATTN: MT-S
Dugway, UT 84022

Head, Rsch and Development Div (ESA-131)
Meteorological Department
Naval Weapons Engineering Support Act
Washington, DC 20374

Commander
US Army Electronics Command
ATTN: DRCDE-R
5001 Eisenhower Avenue
Alexandria, VA 22304

Marine Corps Dev & Educ Cmd
Development Center
ATTN: Cmd, Control, & Comm Div (C^3)
Quantico, VA 22134

Commander
US Army Electronics Command
ATTN: DRSEL-WL-D1
Fort Monmouth, NJ 07703

Commander
US Army Missile Command
ATTN: DRSMI-RFGA, B. W. Fowler
Redstone Arsenal, AL 35809

Dir of Dev & Engr
Defense Systems Div
ATTN: SAREA-DE-DDR
H. Tannenbaum
Edgewood Arsenal, APG, MD 21010

Mr. William A. Main
USDA Forest Service
1407 S. Harrison Road
East Lansing, MI 48823

Naval Surface Weapons Center
Technical Library and Information
Services Division
White Oak, Silver Spring, MD 20910

Dr. A. D. Belmont
Research Division
PO Box 1249
Control Data Corp
Minneapolis, MN 55440

Dir, Elec Tech and Devices Lab
US Army Electronics Command
ATTN: DRSEL-TL-D, Bldg 2700
Fort Monmouth, NJ 07703

Director
Development Center MCDEC
ATTN: Firepower Division
Quantico, VA 22134

Commander
US Army Proving Ground
ATTN: Technical Library, Bldg 2100
Yuma, AZ 85364

US Army Liaison Office
MIT-Lincoln Lab, Library A-082
PO Box 73
Lexington, MA 02173

Library-R-51-Tech Reports
Environmental Research Labs
NOAA
Boulder, CO 80302

Head, Atmospheric Research Section
National Science Foundation
1800 G. Street, NW
Washington, DC 20550

Commander
US Army Missile Command
ATTN: DRSMI-RR
Redstone Arsenal, AL 35809

Commandant
US Army Field Artillery School
ATTN: Met Division
Fort Sill, OK 73503

Meteorology Laboratory
AFCRL/LY
Hanscom AFB
Bedford, MA 01731

Commander
US Army Engineer Topographic Lab
(STINFO CENTER)
Fort Belvoir, VA 22060

Commander
US Army Missile Command
ATTN: DRSMI-RRA, Bldg 7770
Redstone Arsenal, AL 35809

Air Force Avionics Lab
ATTN: AFAL/TSR
Wright-Patterson AFB, Ohio 45433

Commander
US Army Electronics Command
ATTN: DRSEL-VL-D
Fort Monmouth, NJ 07703

Commander
USAICS
ATTN: ATSI-CTD-MS
Fort Huachuca, AZ 85613

E&R Center
Bureau of Reclamation
ATTN: Bldg 67, Code 1210
Denver, CO 80225

HQDA (DAEN-RDM/Dr. De Percin)
Forrestal Bldg
Washington, DC 20314

Commander
Air Force Weapons Laboratory
ATTN: AFWL/WE
Kirtland AFB, NM 87117

Commander
US Army Satellite Comm Agc
ATTN: DRCPM-SC-3
Fort Monmouth, NJ 07703

Commander
US Army Electronics Command
ATTN: DRSEL-MS-TI
Fort Monmouth, NJ 07703

Commander
US Army Electronics Command
ATTN: DRSEL-GG-TD
Fort Monmouth, NJ 07703

Dr. Robert Durrenberger
Dir, The Lab of Climatology
Arizona State University
Tempe, AZ 85281

Commander
Headquarters, Fort Huachuca
ATTN: Tech Ref Div
Fort Huachuca, AZ 85613

Field Artillery Consultants
1112 Becontree Drive
ATTN: COL Buntyn
Lawton, OK 73501

Commander
US Army Nuclear Agency
ATTN: ATCA-NAW
Building 12
Fort Bliss, TX 79916

Director
Atmospheric Physics & Chem Lab
Code 31, NOAA
Department of Commerce
Boulder, CO 80302

Dr. John L. Walsh
Code 5503
Navy Research Lab
Washington, DC 20375

Commander
US Army Air Defense School
ATTN: C&S Dept, MSLSCI Div
Fort Bliss, TX 79916

Director National Security Agency
ATTN: TDL (C513)
Fort George G. Meade, MD 20755

USAF EPAC/CBT (Stop 825)
ATTN: Mr. Burgmann
Scott AFB, IL 62225

Armament Dev & Test Center
ADTC (DLOSL)
Eglin AFB, Florida 32542

Commander
US Army Ballistic Rsch Labs
ATTN: DRXBR-IB
Aberdeen Proving Ground, MD 21005

Director
Naval Research Laboratory
Code 2627
Washington, DC 20375

Commander
Naval Elect Sys Cmd HQ
Code 51014
Washington, DC 20360

The Library of Congress
ATTN: Exchange & Gift Div
Washington, DC 20540
2

CO, US Army Tropic Test Center
ATTN: STETC-MO-A (Tech Lib)
APO New York 09827

Commander
Naval Electronics Lab Center
ATTN: Library
San Diego, CA 92152

Office, Asst Sec Army (R&D)
ATTN: Dep for Science & Tech
Hq, Department of the Army
Washington, DC 20310

Director
US Army Ballistic Research Lab
ATTN: DRXBR-AM, Dr. F. E. Niles
Aberdeen Proving Ground, MD 21005

Commander
Frankford Arsenal
ATTN: Library, K2400, Bldg 51-2
Philadelphia, PA 19137

Director
US Army Ballistic Research Lab
ATTN: DRXBR-XA-LB
Bldg 305
Aberdeen Proving Ground, MD 21005

Dir, US Naval Research Lab
Code 5530
Washington, DC 20375

Commander
Office of Naval Research
Code 460-M
Arlington, VA 22217

Commander
Naval Weather Service Command
Washington Navy Yard
Bldg 200, Code 304
Washington, DC 20374

Technical Processes Br
D823
Room 806, Libraries Div NOAA
8060 13th St
Silver Spring, MD 20910

The Environmental Rsch Institute of MI
ATTN: IRIA Library
PO Box 618
Ann Arbor, MI 48107

Redstone Scientific Info Center
ATTN: Chief, Documents
US Army Missile Command
Redstone Arsenal, AL 35809

Commander
Edgewood Arsenal
ATTN: SAREA-TS-L
Aberdeen Proving Ground, MD 21010

Sylvania Elec Sys Western Div
ATTN: Technical Reports Library
PO Box 205
Mountain View, CA 94040

Commander
US Army Security Agency
ATTN: IARD-OS
Arlington Hall Station
Arlington, VA 22212
2

President
US Army Field Artillery Board
Fort Sill, OK 73503

Commandant
US Army Field Artillery School
ATTN: ATSF-TA-R
Fort Sill, OK 73503

CO, USA Foreign Sci & Tech Center
ATTN: DRXST-ISI
220 7th Street, NE
Charlottesville, VA 22901

Commander, Naval Ship Sys Cmd
Technical Library, Rm 3 S-08
National Center No. 3
Washington, DC 20360

Commandant
US Army Signal School
ATTN: ATSN-CD-MS
Fort Gordon, GA 30905

Rome Air Development Center
ATTN: Documents Library
TILD (Bette Smith)
Griffiss Air Force Base, NY 13441

HQ, ESD/DRI/S-22
Hanscom AFB
MA 01731

Commander
Frankford Arsenal
ATTN: J. Helfrich PDSP 65-1
Philadelphia, PA 19137

Director
Defense Nuclear Agency
ATTN: Tech Library
Washington, DC 20305

Department of the Air Force
5WW/DOX
Langley AFB, VA 23665

Commander
US Army Missile Command
ATTN: DRSMI-RER (Mr. Haraway)
Redstone Arsenal, AL 35809

CPT Hugh Albers, Exec Sec
Interdept Committee on Atmos Sci
Fed Council for Sci & Tech
National Sci Foundation
Washington, DC 20550

US Army Research Office
ATTN: DRXRO-IP
PO Box 12211
Research Triangle Park, NC 27709

Commander
US Army Training & Doctrine Cmd
ATTN: ATCD-SC
Fort Monroe, VA 23651

Mil Assistant for Environmental Sciences
OAD (E & LS), 3D129
The Pentagon
Washington, DC 20301

Commander
Eustis Directorate
US Army Air Mobility R&D Lab
ATTN: Technical Library
Fort Eustis, VA 23604

National Weather Service
National Meteorological Center
World Weather Bldg - 5200 Auth Rd
ATTN: Mr. Quiroz
Washington, DC 20233

Commander
US Army Materiel Command
ATTN: DRCRD-SS (Mr. Andrew)
Alexandria, VA 22304

Commander
Frankford Arsenal
ATTN: SARFA-FCD-O, Bldg 201-2
Bridge & Tarcony Sts
Philadelphia, PA 19137

Inge Dirmhirn, Professor
Utah State University, UMC 48
Logan, UT 84322

Chief, Aerospace Environ Div
Code ES41
NASA
Marshall Space Flight Center, AL 35802

Dr. Frank D. Eaton
PO Box 3038
University Station
Laramie, Wyoming 82071

Commander
US Army Arctic Test Center
ATTN: STEAC-OP-PL
APO Seattle 98733

Commander
US Army Electronics Command
ATTN: DRSEL-GS-H (Stevenson)
Fort Monmouth, NJ 07703

Commander
USACACDA
ATTN: ATCA-CCC-W
Fort Leavenworth, KS 66027

Commander
US Army Test & Eval Cmd
ATTN: DRSTE-FA
Aberdeen Proving Ground, MD 21005

Air Force Cambridge Rsch Labs
ATTN: LKI
L. G. Hanscom Field
Bedford, MA 01730

Director, Systems R&D Service
Federal Aviation Administration
ATTN: ARD-54
2100 Second Street, SW
Washington, DC 20590

USAFETAC/CB (Stop 825)
Scott AFB
IL 62225

Director
USAE Waterways Experiment Station
ATTN: Library
PO Box 631
Vicksburg, MS 39180

Defense Documentation Center
ATTN: DDC-TCA
Cameron Station (BLDG 5)
Alexandria, Virginia 22314
12

Commander
US Army Electronics Command
ATTN: DRSEL-CT-S
Fort Monmouth, NJ 07703

Commander
Holloman Air Force Base
6585 TG/WE
Holloman AFB, NM 88330

Commandant
USAFAS
ATTN: ATSF-CD-MT (Mr. Farmer)
Fort Sill, OK 73503
2

Commandant
USAFAS
ATTN: ATSF-CD-C (Mr. Shelton)
Fort Sill, OK 73503
2

Commander
US Army Electronics Command
ATTN: DRSEL-CT-S (Dr. Swingle)
Fort Monmouth, NJ 07703
3

☆ U.S. GOVERNMENT PRINTING OFFICE: 1976—777-022/6